CR 165204

SPHERICAL

ROLLER BEARING ANALYSIS

SKF COMPUTER PROGRAM "SPHERBEAN"

VOLUME II: USER'S MANUAL

DECEMBER 1980

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SKF REPORT NO: AT81D007 SKF PROGRAM NO: AT81Y001

(NASA-CR-165204) SPHERICAL ROLLER BEARING ANALYSIS. SKF COMPUTER PROGRAM SPHERBEAN. VOLUME 2: USER'S MANUAL Final Report, Jun. 1978 - Dec. 1980 (SKF Technology Services) 150 p HC A07/MF A01 CSCL 13I G3/37 N82-20541 Unclas 09304

SUBMITTED TO:

NATIONAL AERONAUTICS & SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
21000 BROOKPARK ROAD
CLEVELAND, OH 44135

UNDER CONTRACT NO. NAS3-20824

SUBMITTED BY:

SKF INDUSTRIES, INC.
TECHNOLOGY SERVICES
1100 FIRST AVENUE
KING OF PRUSSIA, PA. 19406

1. Report No. CR-165 204	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle SKF Computer Program SPHERBEAN Volume II: User's Manual		5. Report Date December 1980
		6. Performing Organization Code
7. Author(s) Robert J. Kleckner and George Dyba		8. Performing Organization Report No. AT81D007
		10. Work Unit No.
9. Performing Organization Name and Address SKF Industries, Inc. Technology Services 1100 First Avenue King of Prussia, Pa. 19406		11. Contract or Grant No. NAS-20824
		13. Type of Report and Period Covered Final Report/ June 1978 - December 1980
12. Sponsoring Agency Name and Address NASA/Lewis Research Center 21000 Brookpark Road Cleveland, Ohio 44135		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The objective of this three volume report is to describe the use of a fully operational computer program which will predict the thermomechanical performance characteristics of high speed lubricated double row spherical roller bearings. The analysis allows six degrees of freedom for each roller and three for each half of an optionally split cage. Roller skew, free lubricant, inertial loads, appropriate elastic and friction forces, flexible outer ring, etc. are considered. Roller quasidynamic equilibrium is calculated for a bearing with up to 30 rollers per row, and distinct roller and flange geometries are specifiable. Software performance is verified by correlation with results of hardware testing.

Volume I describes the models and associated mathematics used within SPHERBEAN. The user is referred to the material contained there for formulation assumptions and algorithm detail.

Volume III describes the results of a series of full scale hardware tests, and demonstrates the degree of correlation between performance predicted by SPHERBEAN and measured data.

The material present in this, Volume II, is structured to guide the user in the practical and correct implementation of SPHERBEAN. Input and output, guidelines for program use and sample executions are detailed.

17. Key Words (Suggested by Author(s)) Spherical Roller Bearing Computer Simulation Spherical Planet Bearing Roller Skew High Speed Thermal Analysis	18. Distribution Statement		
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*

* For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-C-168 (Rev. 10-75)

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Released:

SKF REPORT NO: AT81D007
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FOREWORD

This, Volume II of the report, "Spherical Roller Bearing Analysis," details information required to use the design and analysis computer program SPHERBEAN. All efforts involved in the generation of the code were accomplished under contract NAS3-20824 issued by the NASA-Lewis Research Center of Cleveland, Ohio, under the administration of the Structures and Mechanical Technologies Division. Funding was provided by the Product Assurance Office of the Army Aviation Research and Development Command, St. Louis, Missouri. The technical monitor was Mr. H. H. Coe. The work was performed at SKF Industries, Inc., King of Prussia, Pennsylvania, during the period June, 1978 through December 1980.

Technical project leadership was executed by Mr. R. J. Kleckner, with contributions from: Dr. J. Pirvics, Messrs. G. Dyba, T. Deromedi and Ms. M. M. Dinon.

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SPHERICAL ROLLER BEARING ANALYSIS

1.0 INTRODUCTION

SPHERBEAN (SPHERical BEaring ANalysis) has been created to simulate the performance of double row spherical roller bearings, Figure 1, under a variety of operating conditions. Emphasis has been placed on detailing the effects of roller skew, roller end to flange contact and change in clearance as functions of speed, mounting fits and temperature.

The complete range of EHD contact considerations has been treated in the computation of raceway and flange contact detail. A flexible outer ring option is made available for simulation of planet bearing performance, where the bearing's outer ring is integral with the planet gear. Program capabilities also include both, steady state and time transient temperature mapping of a spherical bearing system.

Volume I of this three volume report [1][1] describes the models and associated mathematics used within SPHERBEAN. The user is referred to the material contained therein for formulation assumptions and algorithm detail. Volume III [2] describes the results of a series of full scale hardware tests, and demonstrates the degree of correlation between performance predicted by SPHERBEAN

[1] Numbers in brackets refer to references at end of report.

and measured data.

The material present in this, Volume II, is structured to guide the user in the correct and practical implementation of SPHERBEAN. Input and output, guidelines for program use and sample executions are detailed in the matter which follows.

2.0 INPUT DATA

SPHERBEAN requires the preparation of input data which in general describes the bearing geometry, properties of the materials used, and specifies the imposed operating conditions.

SPHERBEAN'S input data preprocessor has been structured to impose minimal initial demands on the user. Data is segregated into sets, or CATEGORIES, which individually address specific features of the system addressed. Any data set item required by the program falls into one of nine distinctly identified categories (Table 1). Category "ROLLR" for example, contains all roller geometry data. Category "CAGE" details cage information. Items detailing planetary gear parameters are entered into input category "GEAR".

All data required by the basic program are accepted in free NAMELIST format and default values are hardcoded to minimize the demands on user judgement. Special input data, required when the program options are used, is in 80 column card image format.

In each CATEGORY, the user has the freedom to specify all, part, or none of the data. If an item of data is omitted, a default value is assumed. A list of these default values is shown in Table 2. Failure to include certain basic data, e.g., groove radius, load, speed, etc. results in a diagnostic abort message.

Data comprising a category are specified in free format, with the restrictions that: (1) column one of any card is not used and (2) all items of data in any CATEGORY are separated by commas[2]. No specific sequence of data is required within each CATEGORY. A minimum of two cards is needed to specify a complete set of data within a CATEGORY.

As an example, consider CATEGORY nine, "LIFE." Here, surface finish and fatigue life data are described. Five of the required items are:

1. RMSROL - The RMS surface roughness of the rollers.
2. RMSIR - The RMS surface roughness of the inner raceway.
3. RMSOR - The RMS surface roughness of the outer raceway.
4. CIR - User supplied life multiplier for the inner raceway.
5. COR - User supplied life multiplier for the outer raceway.

An example of free format input data is illustrated for CATEGORY LIFE in Figure 2. The first card contains a dollar

[2] On some computers the commas must follow the last significant digit of an input variable. It is suggested that this restriction be observed to avoid the inconvenience caused by compiler peculiarities.

sign ($)[3] in column 2 followed immediately by the CATEGORY name LIFE. The second and third card are used to specify values of input data. Note that free format is used throughout and that all data items are separated by a comma. The third card contains a Dollar Sign ($) in column 2 and the word END in columns 3 through 5 signifying the end of data for the category. Note that column 1 of any card was never used to specify data.

Each data category is used to describe a particular aspect of either program use or the bearing configuration. Categories, in turn, must be arranged in the sequence noted in Table 1 before they can be used to transmit data to the program.

The following paragraphs will list, in their proper order, all categories and the data they contain. In certain cases where, at the user's option, categories can be omitted from the set, these options are made clear. Likewise, it is also indicated when a category must be included, regardless of execution options. If the user wishes to omit a category of data, he must still include the two cards:

$CATEGORY NAME
$END

---

[3] Different computers may allow or require a different symbol. For example, an IBM 370/158 uses an ampersand (&); a UNIVAC 1108 uses the dollar sign ($).

CATEGORY 1 - PROGRAM LOGIC

CATEGORY NAME: LOGIC

CATEGORY DESCRIPTION

Within this category, the user is permitted to specify values for logic used in a given program execution. User provided values dictate the program options.

All variables in this category are "logical," and have either of two values, .TRUE. or .FALSE. e.g., SYMY = .TRUE..

In many cases, additional data will be required from the user as a consequence of selecting a specific program option. Descriptions of extra input data may be found in the Section "SPECIAL INPUT DATA," starting on page 28.

DATA ITEMS:		DEFAULT:
FLGIR	- Used to identify a spherical roller bearing having a flanged inner ring.	F
PLTROL	- Allows the user to obtain a line printer plot of the roller profile along its axial effective length.	F
ECHO	- Allows the user to echo check the input data. This option involves routines which print the data immediately after it has been read.	T

DATA ITEMS:		DEFAULT:
SPLTCG	- Used to execute the split, two piece cage analysis portion of the program. The following restrictions must be observed when employing the split cage analysis: • use only for pure axial or combined loading. Under pure radial loading, each row of the two row bearing is assumed to behave identically. • use only at solution level 3 or 4 (LEVEL = 3 or LEVEL = 4 in Category "SOLVE") • do not use with PLANET = .TRUE., since each row of a two row planetary bearing is assumed to behave identically.	F
PLANET	- Used to indicate that the bearing to be simulated is employed in a planetary gear application. If .TRUE., the user must supply the data items for category 5, "GEAR " ("GEAR" described on page 18).	F
METRIC	- If .TRUE., input data items are being supplied in Metric (M - K - S) units; if .FALSE., English (F - P - S) units are used. Program output is dimensionally consistent with user input.	T

Special Program Option Logic:

The following five data items allow the user to in-

voke certain program options. All items require the user to include additional data if a value other than the default value is specified (see "SPECIAL INPUT DATA").

DATA ITEMS:		DEFAULT:
FITS	- If .TRUE., the bearing's operating diametral clearance is computed as a function of temperature, speed and initial mounting fit pressure. If .FALSE., the clearance change analysis is not executed and the user input diametral clearance ("DCL" in Category 4) is used in calculating bearing details.	F
MPROP	- Allows the user to input material properties for the rings, rollers, shaft and housing.	F
SYMY	- A .TRUE. value indicates that the roller is symmetric about its y-axis. If SYMY is .FALSE., the non-symmetric roller profile must be read in.	T
EVSLIC	- The program uses a slicing technique to compute the roller-raceway loads. By default all slices are of equal width. In many cases it may be advantageous to specify slices of unequal width. Unequal slice widths specifying EVSLIC = .FALSE. .	T
THERM	- A .TRUE. value allows the user to use either the steady state or time transient temperature calculating routines.	F

CATEGORY 2 - SOLUTION CONTROL PARAMETERS

CATEGORY NAME: SOLVE

CATEGORY DESCRIPTION

Computer program SPHERBEAN uses a modified Newton-Raphson iterative scheme to compute values for the governing equilibrium equation set. The user may wish to override existing solution control parameters. Those which are permitted as input by the user are contained within this category.

DATA ITEMS: DEFAULT:

TOL - Convergence criterion used to halt the iteration procedure. Solution is said to be obtained when (default: .05)

$$\left[\left(\sum_{i=1}^{N} EQ_i^2\right)/N\right]^{1/2} \leq TOL$$

where EQ_i = residue for ith equation

N = number of equations to be solved

NITS - Maximum number of iterations to be used in the Newton-Raphson iteration scheme. (default: 20)

LEVEL - Solution control level: (default: 1)

LEVEL = 1: Inner ring and roller equilibrium is mutually satisfied through consideration of the elastic (Hertzian) contact loads at all roller-race contacts. Rollers are permitted to translate radially, and rotate about their z-axis (roller tilt). The inner

DATA ITEMS:

ring may translate along each of its three coordinate axes. This execution level will permit economic calculation of bearing life. Lubricant and friction related loads are not considered; epicyclic roller speeds are assumed.

LEVEL = 2: Mutual equilibrium of rollers and inner ring is sought as in Level 1, then used to evaluate the lubricant related forces (EHD, HD, drag, and cage pocket). This level of execution permits an economic estimation of bearing generated heat. Epicyclic roller speeds are assumed.

LEVEL = 3: Two solution algorithms are used to evaluate the bearing performance. The first seeks mutual equilibrium of inner ring and rollers by varying the inner ring position and roller radial, axial and tilt positions. The second algorithm seeks mutual equilibrium of the rollers and cage by varying the cage position and roller skew, tilt and rotational speeds.

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DATA ITEMS: DEFAULT:

This level of execution provides an economic method of evaluating bearing performance when there is little or no rolling element skidding and can be used to predict the existence of such skidding, but not its absolute magnitude. Note that at this level of execution, the inner ring reactive load may not exactly equilibrate with the applied loading.

LEVEL = 4: The two algorithms used in Level 3 are repeated until mutually satisfied. This assures equilibrium of the inner ring with applied loading. This execution level can be used to predict the presence and magnitude of rolling element skidding.

PRINT - Debug output print flag. Allows the user to see calculated results, in English units, at intermediate steps of solution. The PRINT array may be input with the following logical variables:

PRINT (1)=.TRUE. - Displays algorithm number, number of equations to be solved, and variables and F

DATA ITEMS:			DEFAULT:
		equations included in partition of field equation set.	
PRINT(2)=.TRUE.	-	Elastohydrodynamic (EHD) friction coefficients are printed.	F
PRINT(3)=.TRUE.	-	Roller centrifugal forces are printed.	F
PRINT(4)=.TRUE.	-	Roller gyro-moments are printed.	F
PRINT(5)=.TRUE.	-	Print the corrections of the variable values as calculated in the NR equation solver.	F
PRINT(6)=.TRUE.	-	Print the matrix of partial derivatives (caution: large volume output can be expected)	F
PRINT(7)=.TRUE.	-	Print the X and EQ values about which partial derivatives are computed.	F
PRINT(8)=.TRUE.	-	Print the current NR loop statistics.	F
PRINT(9)=.TRUE.	-	Displays divergence messages, intermediate equation residues (EQ), roller-raceway loads and moments, roller independent (X) variables, and the solution algorithm number.	F
PRINT(10)=.TRUE.	-	Print cage loads and moments.	F

DATA ITEMS:		DEFAULT:
<u>CAGDOF</u> -	Number of degrees of freedom to be used in the cage analysis. Allowable integer values are either 1 or 3. The one degree-of-freedom cage permits cage rotational movement about its longitudinal center line; three degrees-of-freedom permit translation in the radial plane and rotation about the centerline. Note that in cases of pure axial loading, the cage will behave symmetrically and only one degree-of-freedom will be employed.	1

CATEGORY 3 - ROLLER GEOMETRY DATA

CATEGORY NAME: ROLLR

CATEGORY DESCRIPTION:

Within this category the user must describe the geometry of the rolling elements within the bearing complement. This category is always included. Dimensional units are shown in parentheses, i.e. (inches[millimeters]), where the term in brackets represents "metric" system input; roller geometry is illustrated in Fig. 3.

DATA ITEMS:		DEFAULT:
NS	- Number of roller raceway slices used in the analysis. Note: If the user specifies symmetry about the roller y-axis, i.e. SYMY=.TRUE. in category "LOGIC," then NS is the number of slices per symmetric half. If the user specifies no symmetry then NS is the total number of slices.	5
HRD	- Roller maximum diameter (in[mm])	None
ELO	- Effective length of the roller to outer ring contact[4] (in[mm])	None
ELI	- Effective length of the roller to inner ring contact[4] (in[mm])	None

[4]The effective contact length refers to the longest possible length which can be used to transmit load between the roller and raceway. Typically, this is the roller total length less corner radii. If, however, the raceway undercuts are exceptionally large so that the track width is less than the roller effective length then the track width should be input.

DATA ITEMS: DEFAULT:

Item	Description	Default
FLENTH	- Roller flat length (in[mm])	None
RCC	- Roller crown radius (in[mm])	None
KLUCRN	- Roller geometry flag having the following possible values:	2

KLUCRN = 1; The roller active profile is either fully flat or crowned with a flat. Symmetry about the y-axis is assumed.

KLUCRN = 2; The roller active profile is spherical with y-symmetry (KLUCRN=2 is applicable to the roller shown in Figure 3).

KLUCRN = 3; The roller active profile is symmetric about the y-axis and will be read in by the user. (See "SPECIAL INPUT DATA").

KLUCRN = 4; The roller active profile is non-symmetric about the y-axis and will be read in by the user (See "SPECIAL INPUT DATA").

Item	Description	Default
PHI1	- Angular location of the first rolling element in the first row of a double row bearing. In the nomenclature of Figure 4, the angle is measured CCW positive from the bearing y-axis. Input is in degrees.	0
PHI2	- Angular location of the first rolling element in the second row.	0

DATA ITEMS:		DEFAULT:
NUMROL	- Number of rollers per row.	None
REND	- Roller end sphere radius Iin[mm])	0
RSREX1	- The x-coordinate of the origin of the roller end sphere radius, for rollers in row 1 (in[mm])	0
RSREX2	- The x-coordinate of the origin of the roller end sphere radius, for rollers in row 2 (in[mm])	0
ENDPLY	- Roller-flange end play (in[mm]) See Figure 5.	0

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CATEGORY 4 - RING DATA AND BEARING APPLIED LOAD

CATEGORY NAME: RNGEO

CATEGORY DESCRIPTION:

Within this category the user must specify inner and outer ring geometry, inner ring speed and operating load This data set must always be included. (See Figures 5 and 6).

DATA ITEMS:		DEFAULT:
GROR	- Outer ring groove radius (in[mm]).	0
GRIR	- Inner ring groove radius (in[mm]).	0
DCL	- Bearing diametral clearance (in[mm]).	0
ALPHA	- Absolute value of contact angle (radians)	0
SPDIR	- Inner ring rotational speed (rpm)[5]	0
FLGANG	- Flange angle (radians)	0
FX	- Axial load in X direction (lbs[N])[5]	0
FY	- Radial load in Y direction (lbs[N])[5]	0
FZ	- Radial load in Z direction (lbs[N])[5]	0

[5]These data items can be omitted if simulating a planetary bearing, i.e. PLANET = .TRUE. in Category 1, "Program Logic." Load and speed information are entered in Category 5, "Planet Bearing Data."

CATEGORY 5 - PLANETARY BEARING DATA

CATEGORY NAME: GEAR

CATEGORY DESCRIPTION:

SPHERBEAN has the capability to analyze double row, spherical planet bearings (Figure 7). In this application, the bearing outer ring is integral with a gear, and load is transmitted to the bearing through a pair of diametrally opposed gear meshes, Figure 8. SPHERBEAN will also compute the effects of carrier motion on bearing performance by consideration of centrifugal forces generated by the kinematics of planetary motion, Figure 9. This data set must be included when PLANET = .TRUE.

DATA ITEMS:		DEFAULT:
NMESH	- Number of gear tooth pairs in simultaneous contact at each mesh. Values of 1, 2 or 3 are permitted.	1
TANGLE	- Angle between teeth on planet gear; TANGLE = 2π/Number of teeth on planet gear (radians).	0
SPDCAR	- Carrier rotational speed (rpm).	0
SPDR1	- Outer ring rotational speed. If carrier speed is input as non-zero, then SPDR1 must be input with a negative sign to maintain proper sign conventions (rpm).	0
NPL	- Number of planet bearings in stage	1

DATA ITEMS:			DEFAULT:
RCAR	-	Radius from sun gear center to post, Figure 9 (in[mm]).	0
XI	-	Cross sectional moment of intertia of planet bearing outer ring, Figure 10. Default is rigid ring (in^4[mm^4]).	0
RNUET	-	Radius, from bearing centerline, to neutral axis of the planet bearing outer ring, Figure 10 (in[mm]).	0
R1, R2, R3	-	Radial component of gear tooth contact load at each of up to 3 teeth in contact, Figures 11 and 12. Number of non-zero input values for load components must equal NMESH. Radial loads are input with a negative sign to maintain sign convention, Volume I [1] of this report (lbs[N]).	
T1, T2, T3	-	Tangential component of gear tooth contact load at each of up to 3 teeth in contact, Figure 11 (lbs[N]).	0
XM1, XM2, XM3	-	Moment component of gear tooth contact load at up to 3 teeth in contact, Figure 11 (in-lbs[Nmm]). Note that XM1=T1(Rp-RNUET).	0
DENS	-	Density of the planet gear bearing outer ring (lbs/in^3[KG/cm^3]).	.28[.007750]
XMASS	-	Weight of the planet gear bearing outer ring (lbs[N]).	0
E	-	Modulus of Elasticity (lbs/in^2[N/mm^2]).	29,500,000 [204,083]

CATEGORY 6 - CAGE DESCRIPTION

CATEGORY NAME: CAGE

CATEGORY DESCRIPTION:

The data items contained within this category are used to describe cage geometry. This set of data must always be included. (See Figure 13).

DATA ITEMS:		DEFAULT:
ITYPE	- Cage type flag ITYPE = 0 ; the cage is rolling element riding ITYPE = 1 ; the cage is outer ring-land riding ITYPE = 2 ; the cage is inner ring-land riding	0
RADCLR	- Pocket radial clearance (in[mm])	0
AXCLR	- Pocket axial clearance (in[mm])	0
WEBT	- Web thickness (in[mm])	0
NRAILS	- Total number of cage guide rails (included for reference only, not used in program).	1
A	- Inside radius of split interface for a two piece cage, Figure 14 (in[mm]).	0
B	- Outside radius of split interface for a two piece cage, Figure 14 (in[mm]).	0
XMU	- Coefficient of friction between split halves of a split cage.	.07

The following data is included if the cage is land riding (ITYPE = 1 or ITYPE = 2):

DATA ITEMS: DEFAULT:

RAILD - Equivalent rail land diameter[6]: 0

$$RAILD = 2a/\ (a^3/b)^{.375}$$

Where

$$a = \sum_{i=1}^{i=NRAILS} (r\ell^3)_i$$

and

$$b = \sum_{i=1}^{i=NRAILS} (r^3\ell)_i$$

r = the rail land radius of the i-th rail (in[mm]).

ℓ = the width of the i-th rail (in[mm]).

RAILW - Equivalent single rail width[6]: 0

$$RAILW = (a^3/b)^{.125}$$

where a and b are defined as above, in definition of variable RAILD.

RCLR - Rail land diametral clearance (in[mm]). 0

---

[6] If performing a split cage analysis, i.e. SPLTCG = .TRUE. in category LOGIC, these data items are computed for only one of the split cage pieces.

CATEGORY 7 - LUBRICATION DATA

CATEGORY NAME: LUBE

CATEGORY DESCRIPTION:

Within this category the user specifies lubricant properties and other data which relate directly to the lubricant or to the definition of friction related processes. This category should always be included.

DATA ITEMS:		DEFAULT:
NCODE	- The user is given the option to specify particular lubricant propties or simply select a value of 1 through 4 for NCODE. Specific values of NCODE and associated lubricant properties are shown in Table 3. The user may input lubricant properties not in Table 3 by specifying NCODE = 0, and including the five specific lubricant properties on page 61.	4
ZTO, ZTI, ZTFL	- Lubricant replenishment layer thickness[7] at the outer raceway, inner raceway and the flange,	$20. \times 10^{-6}$ [5.08×10^{-4}]

[7] At the present time the magnitudes of the inner and outer replenishment layer thicknesses have not been correlated with flow rate, particular lubricants or bearing speed. The user is required to establish proper values of the replenishment layer thickness. The following guidelines are suggested:
- To avoid starvation ZTO,ZTI,ZTFL should be 1 or 2 times the EHD film thickness
- Centrifugal loading suggests ZTO be larger than ZTI.

DATA ITEMS:		DEFAULT:
	respectively (in/mm). Note: if ZTO = ZTI = ZTFL = 0.0 dry friction is assumed.	
FRK	- Lubricant pseudo friction coefficient, used in the Allen [3] traction model. Typical values lie in the range 0.5 ⩽ FRK ⩽ .08.	.07
AKN	- SPHERBEAN uses a model developed by Loewenthal [4] to compute EHD film thickness. The term AKN, the lubricant film thickness coefficient, appears in that equation. Typical values are 18.2 ⩽ AKN ⩽ 50.	18.2
XMURC	- Dry coefficient of friction at race contacts. If ZTO=ZTI=0, XMURC is applied.	.075
XMUFL	- Dry coefficient of friction at the flange contact. If ZTFL = 0, XMUFL is applied.	.075
XMUCG	- Coulomb friction coefficient used at the cage pocket-rolling element contact. If ZTO=ZTI=0, XMUCG is applied.	.075
XCAV	- Percent of lubricant occupying the bearing cavity[8]. 0. ⩽ XCAV ⩽ 100.	1.

[8] As with replenishment layer thickness, the amount of free lubricant should be correlated with the operating parameters. At this time, such correlations do not exist. XCAV values of less than 5 percent are recommended.

DATA ITEMS:			DEFAULT:
BRKPT	-	Limiting value of slide-to-roll ratio used in calculating friction forces with the Allen [3] traction model when the critical shear stress is exceeded.	0.005

The following data items must be included if NCODE was specified as zero.

DATA ITEMS:			DEFAULT:
RH060	-	Density of lubricant (gm/cm^3) at 60°F.	None
G	-	Thermal coefficient of expansion (1°F).	None
VIS100	-	Viscosity of lubricant (centistokes) at 100°F.	None
VIS210	-	Viscosity of lubricant (centistokes) at 210°F.	None
COND	-	Thermal conductivity (BTU/hr-ft-°F)	None

CATEGORY 8 - OPERATING TEMPERATURES

CATEGORY NAME: TEMPS

CATEGORY DESCRIPTION:

Operating temperatures are defined in this category. Outer race, inner race and flange temperatures are used to evaluate the properties of the specified lubricant at these locations. Bulk temperature (BULK) is used to evaluate the properties of the lubricant contained in the free space of the bearing cavity. This information is subsequently used in the calculation of the viscous drag force acting upon the rolling elements. Data for this category must be included unless performing a thermal analysis, i.e. THERM = .TRUE. in category LOGIC. Temperatures are specified in either ^{o}F or ^{o}C.

DATA ITEMS: (See Figure 15)		DEFAULT:
RING11	- Outer ring temperature for row no. 1.	212.[100.]
RING12	- Outer ring temperature for row no. 2.	212.[100.]
RING21	- Inner ring temperature for row no. 1.	212.[100.]
RING22	- Inner ring temperature for row no. 2.	212.[100.]
BULK	- Average temperature of lubricant in bearing cavity.	212.[100.]
FLG1	- Inner ring flange temperature for row no. 1.	212.[100.]

DATA ITEMS:		DEFAULT:
FLG2	- Inner ring flange temperature for row no. 2.	212.[100.]
SHAFT	- Shaft temperature	212.[100.]
HOUSE	- Housing temperature	212.[100.]
ROLL1	- Temperature of the rollers for row no. 1.	212.[100.]
ROLL2	- Temperature of the rollers for row no. 2.	212.[100.]
RACE11	- Outer race temperature for row no. 1.	212.[100.]
RACE12	- Outer race temperature for row no. 2.	212.[100.]
RACE21	- Inner race temperature for row no. 1.	212.[100.]
RACE22	- Inner race temperature for row no. 2.	212.[100.]
CAGE1	- Cage temperature for row no. 1.	212.[100.]
CAGE2	- Cage temperature for row no. 2.	212.[100.]

CATEGORY 9 - SURFACE FINISH AND FATIGUE LIFE DATA

CATEGORY NAME: LIFE

CATEGORY DESCRIPTION:

Self-explanatory. This category must always be included.

DATA ITEMS:		DEFAULT:
RMSROL	- The RMS surface roughness of the roller (in[microns])	$8x10^{-6}$[.20]
RMSIR	- The RMS surface roughness of the inner ring (in[microns])	$10x10^{-6}$[.25]
RMSOR	- The RMS surface roughness of of the outer ring.(in[microns])	$10x10^{-6}$[.25]
RMSFL	- The RMS surface roughness of the flange (in[microns])	$10x10^{-6}$[.25]
RMSRE	- The RMS surface roughness of the roller end (in[microns])	$10x10^{-6}$[.25]
CIR	- Life correction factor[9] for the inner ring.	1.
COR	- Life correction factor[9] for the outer ring.	1.

[9] The numbers input for CIR and COR are used to account for improved materials by multiplying the raceway fatigue lives as calculated by Lundberg-Palmgren methods. Typical life factor values for modern steels are in the range of 2 to 3.

In the ASME Publication Life Adjustment Factors for Ball and Roller Bearings, the Material Factor D and the Material Process Factor E should be used multiplicatively as inputs for CIR and COR.

3.0 SPECIAL INPUT DATA

The user activates the extended program capabilities by invoking a maximum of up to six program options. Logic used to activate a given option was presented in the previous section, and is summarized in Table 4.

The user may employ as many options as necessary in a single program execution. The only restrictions are found in the input data sequence shown in Table 4 and the use of the specific 80 column card formats detailed in Appendix A.

All options require the user to specify additional information. This data follows immediately after the basic categorized data.

3.1 OPTION 1: COMPUTATION OF BEARING OPERATING DIAMETRAL CLEARANCE

This data should be included only if the change in bearing diametral clearance, from "off the shelf" to operating value is to be calculated. This option is invoked by specifying FITS = .TRUE. in category LOGIC. The user must supply effective widths and radii of the bearing components, shaft and housing. Positive values should be used for interference fits and negative for clearance (measured on the radius). All data must be given in the cold state (68°F).

Card formats for data input are shown in Figure A1. Input data items are defined in Figure A1A.

3.2 OPTION 2: USER SPECIFIED MATERIAL PROPERTIES

The user may specify the material properties of bearing components by setting the logical variable MPROP = .TRUE.. Appropriate properties are input according to the card format shown in Figure A2. Unspecified variables (i.e. those set to zero or left blank) are assigned the following values:

Modulus of Elasticity	204083 N/mm^2 (2.959988x10^{7}psi)
Poisson's Ratio	0.3
Coefficient of Thermal Expansion	1.124 x 10^{-5} per ^{o}C (6.744 x 10^{-6} per ^{o}F)
Density	7.806 gm/cm^3 (0.28 lb/in^3)

3.3 OPTION 3: USER SPECIFIED SLICE WIDTHS

SPHERBEAN uses the slicing technique (see Volume 1 [1] of this report) to compute the roller to raceway contact traction forces. Ordinarily, the slice widths are assumed equal, however, in some instances it may be advantageous to specify their individual and varying extent.

This option may be invoked by specifying SYMY = .TRUE. and EVSLIC = .FALSE.. Since symmetry is assumed, the slice widths need only be input for a symmetric half of the roller. The numbering scheme used is one where the first slice is encountered at the roller centerline, the last at the roller end, Figure 16. The card format shown in Figure A3 is used for input data.

3.4 OPTION 4: USER INPUT SYMMETRIC ROLLER GEOMETRY

The user may input values for roller radii at specific locations along the roller effective length. The input sequence is shown in Figure 16.

Note that the number of radii to be read in is equal to the number of slices (per symmetric half) plus one. Card formats are given in Figure A4. Logic used is SYMY = .TRUE. and KLUCRN = 3.

3.5 OPTION 5: USER SPECIFIED, COMPLETELY VARIABLE, ROLLER GEOMETRY

The user can specify the complete detail of roller geometry by using the options: SYMY = .FALSE. and KLUCRN = 4.

When using this option the user must specify roller radii and slice widths across both the outer and inner ring effective lengths. Note that the number of radii input corresponds to the total number of slices plus one, Figure 17.

Card formats for data input are shown in Figure A5.

3.6 OPTION 6: TEMPERATURE CALCULATIONS

SPHERBEAN may be used to compute either the time transient or steady state temperature distribution within a system defined by the bearing and its environment. Logic used requires THERM = .TRUE..

The temperature portion of SPHERBEAN is designed to produce temperature maps for an axisymmetric mechanical system of any geometrical shape. The physical system is first approximated by an equivalent "nodal network" which consists of a number of elements having simple geometric shapes. Each element is then represented by a node point characterized by a mass, surface area, and having either a known or an unknown temperature. The environment surrounding the mechanical system is also represented by one or more nodes. With the node points selected, heat balance equations are formulated by the program for the nodes of unknown temperature. These equations become non-linear when there is radiation between two or more of the node points considered.

The success of the approach depends largely on the realistic physical subdivision of the system. If the subdivision is too fine, there will be a large number of equations to be solved, and execution cost will rise. If the subdivision is too crude, the results are likely to be inaccurate.

The present thermal simulation is restricted to the treatment of axially symmetric physical systems. Bearing rings for example, fall into this category and can be represented by an element of uniform temperature. For a component or module which is not axially symmetric, the user must represent it with an equivalent axially symmetric element of approximately the same surface area and material volume.

With input data prepared as described in the following paragraphs, SPHERBEAN will solve the heat-balance equations for either the steady state or the time transient conditions and produce temperature maps for the physical system.

DESCRIPTION OF INPUT DATA FOR TEMPERATURE CALCULATIONS

Card formats for data input are listed in Figures A6.

Card 1

Card 1 is a control card and contains input for both steady state and transient thermal analyses. It is not intended however, that both analyses be executed with the same run.

Item 1: Highest Node Number (M). The temperature nodes must be numbered consecutively from one (1) to the highest node number. The highest node number must not exceed one hundred (100).

Item 2: Number of Unknown Temperature Nodes (N). It is required that all nodes with unknown temperatures be assigned the lowest node numbers. The nodes which have known temperatures are assigned highest numbers.

Item 3: Common Initial Temperature (TEMI)^{o}C: The temperature solution iteration scheme requires a starting point, i.e., guesses of the equilibrium temperatures, however, when a node is not given a specific initial temperature, the temperature specified as Item 3 of Card 1 is assigned.

Item 4: Punch Flag (IPUNCH): If the Punch Flag is not zero (0) or blank, the system steady state equilibrium temperatures, along with the respective node numbers, will be punched according to the format of Card 2. This option is useful if, for instance, the user makes a steady state run with lubrication, and then wishes to use the resultant temperature as the initiation point for a transient dry friction run in order to assess the thermal consequence of lubricant flow termination.

Item 5: "Output Flag" (IUB). If the "Output Flag" is not zero the bearing program output and a temperature map will always be printed after each call to the bearing solution scheme.

Item 6: "Maximum Number of Calls to the Bearing Program" (IT1). IT1 is the limit on the number of Thermal-Bearing iterations, i.e., the external temperature equilibrium calculation.[10] The user must input a non-zero integer such as 5 or 10 for SPHERBEAN to iterate to an equilibrium condition. If IT1 is left blank or set to zero (0), the number of iterations is set to three (3).

IT1 also serves as a limit on the transient temperature solution scheme, by limiting the number of times the bearing solution scheme is called. Each call to the bearing scheme will input a new set of bearing heats to the transient temperature scheme until a steady state condition is approached or until the transient solution time-up limit is reached.

Item 7: "Absolute Accuracy of Temperatures for the External Thermal Solution" (EP1). In the steady state thermal solution scheme, each calculation of system temperatures occurs after a call to the bearing scheme which produces bearing generated heats. After the system temperatures have been calculated for each iteration, using the internal temperature solution scheme, each node temperature is checked against the

[10] See Figure 14 (Volume I [1] of this report) for details of the thermal solution.

nodal temperature at the previous iteration.

If $\{t_{(N)i}-t_{(N-1)i}\} \leq EP1$ for all nodes i then equilibrium has been achieved and the iteration process stops.

Item 8: "Iteration Limit for the Internal Thermal Solution" (IT2). After each call to the bearing analysis, the program will use a Newton-Raphson iteration method to solve the heat balance equations for the steady state equilibrium temperatures, based on the set of bearing heat generation rates. If IT2 is left blank or set to zero (0), the number of Newton-Raphson iterations is limited to twenty (20).

Item 9: "Accuracy for Internal Thermal Solution" (EP2). The use of EP2, the convergence tolerance for the Newton-Raphson procedure described in Item 8, is explained in Volume I.[11] If EP2 is left blank or set to zero (0), a default value of 0.01 is used.

Item 10: "Starting Time" (START) is a time at which the transient solution begins, T_s; usually set to zero (0).

Item 11: "Stopping Time" (STOP) is the time in seconds at which the transient solution terminates, T_f. The transient solution will generate a history of the system performance which

[11] See Figure 14, Volume I [1].

will encompass a total elapsed time of

$$(T_f - T_s) \text{ seconds.}$$

Item 12: "Calculation Time Step" (STEPIN). The transient internal solution scheme solves the system of equations (see Volume I):

$$t_{k+1} = t_k + \frac{q_k}{C_p V} \Delta T$$

$$\Delta T = \text{STEPIN}$$

The user may specify STEPIN. If left blank or set to zero (0), SPHERBEAN calculates an appropriate value for STEPIN using the procedure described in [5].

Item 13: "Time Interval Between Printed Temperature Maps" (TTIME) seconds. The user must specify the length of time which will elapse between each printing of the temperature map. The interval will always be at least as large as the "calculation time step"(STEPIN).

Item 14: "Time Interval Between Calls of the Bearing Program" (BTIME). BTIME will always have a value larger than or equal to (STEPIN) even if the user inadvertently inputs a shorter interval. Computational time savings result if BTIME

is greater than STEPIN, however, accuracy might be lost.

Card 2

In the steady state analysis this card is used to input initial guesses of individual nodal temperatures for unknown nodes as well as the constant temperatures for known nodes, such as ambient air and/or an oil sump.

In the transient analysis, Card 2 is used to input the nodal temperatures of all nodes at time = T_S, i.e., at the initiation of the transient solution.

Card 3

With this card, node numbers are assigned to the components of the bearing. With this information the proper system temperatures are carried into the respective bearing analysis. The inner race and inner ring node numbers may or may not be the same at the user's discretion. Similarly, the outer race and outer ring node numbers may or may not be the same.

Card 4

The bearing analysis accounts for frictional heat generated at different locations in the bearing, i.e., the inner race, the outer race, between the cage rail and ring land, the bulk lubricant due to drag and at the flange. The heat generated at the cage-rolling element contact is added to the

bulk lubricant. This card allows the heat generated to be distributed equally to two nodes. For instance, the heat generated at the inner race-rolling element contact should be distributed half to the rolling element and half to the inner race. The heat developed between the cage and inner ring land may be distributed half to the inner ring and half to the cage if a cage node has been defined, otherwise, half to the bulk lubricant.

Card 5

This card specifies the node numbers and the heat generation rate at those nodes. This card is used to specify where heat is generated at a constant rate such as at rubbing seals or gear contacts.

Card 6

This card type is used to input the numerical values of the various heat transfer coefficients which appear in the equations for heat transfer by conductivity, free convection, forced convection, radiation and fluid flow. Up to ten coefficients of each type may be used. Separate values of each type of coefficient are assigned an index number via card 6. When describing heat flow paths (Card 7 below) it is necessary only to list the index number by which heat transfers between node pairs.

Indices 1-10 are reserved for the <u>conduction</u> coefficient λ, 11-20 for the <u>free convection</u> parameters, 21-30 for <u>forced convection</u>, 31-40 for <u>emissivity</u> and 41-50 for <u>fluid flow</u> (product of specific heat, density and volume flow rate).

As an example, for heat transfer by conduction with coefficient λ of 53.7 watts/M^{o}C one could prepare a card 6 with the digit 1 punched in column 10 and the value 53.7 punched in the field corresponding to card columns 11-20. If a conduction coefficient of 46.7 were applicable for certain other nodes in the system one could punch an additional card assigning index No. 2 to the value λ = 46.7 by punching a "2" in card column 10 and 46.7 anywhere within card columns 11-20.

Rather than providing constant <u>forced convection</u> coefficients, these coefficients can be calculated by the program in one of three ways. If this calculation option is exercised a pair of cards is used in place of a single card containing a fixed value of α. The contents of the pair depends upon which of the three methods are used.

Option 1) α is independent of temperature but is caluclated as a function of the Nusselt number which in turn is a function of the Reynolds number R_e, the Prandtl number P_r as follows, (cf. 5):

$$\alpha = (\lambda_{oil}/L)N_u$$

$$= KR_e^a P_r^b$$

where λ_{oil} is the lubricant conductivity, L is a characteristic length (with the units of meters) and K, a and b are constants.

Option 2) α is a function only of fluid dynamic viscosity and viscosity is temperature dependent.

$$\alpha = c\eta^d$$

where c and d are constants.

Option 3) α is again a function of the Nusselt, Reynolds and Prandtl numbers as in Option 1, but the viscosity is temperature dependent.

Appendix B has been included to aid the user in data preparation and calculation of heat transfer coefficients.

Card 7

This card defines the heat flow paths between pairs of nodes. Every node must be connected to at least one other node, i.e., two or more independent node systems may not be solved with a single program execution.

The calculation of heat transfer areas is based on lengths, L_1 and L_2 input using card 7. Additionally, the type of surface for which the area is being calculated is indicated by the sign assigned to the heat transfer coefficient index.

If the surface is cylindrical or circular, the index should be positive, if the surface is rectangular, the index provided should be a negative integer.

In the case of radiation between concentric axially symmetric bodies, L_3 is the radius of the larger body. For radiation between two parallel flat surfaces or for conduction between nodes, L_3 is the distance between them.

Fluid flow heat transfer computation accounts for the energy which the fluid transports across a node boundary. Surrounding a fluid node at which convection is taking place, the temperature varies. The nodal temperature which is computed is the average of the fluid temperature at the outlet and inlet boundaries. If the emerging temperature of the fluid is of interest, it is necessary to have a fluid node at the fluid outlet. At this auxiliary node, heat transfer occurs by fluid transport only and the fluid temperature is considered to remain throughout the volume it represents. The true fluid outlet temperature will be obtained in this way.

Conduction of heat through a bearing is controlled by index 51. The actual heat transfer coefficient which contains a conductivity, area and a path length term is calculated in the bearing portion of the program.[12] The term is based on a computation which averages the outer race and inner race rolling element contacts.

[12]See Volume I, Appendix C for a detailed description.

4.0 OUTPUT DATA

All data generated by an execution of SPHERBEAN is suitable for output on a 132 character width line printer. Output data is organized so that user supplied information, such as bearing geometry and operating conditions, appears first. Default values for unspecified data are also displayed.

All computed data, representing the results of the analysis performed, is presented after the display of user supplied data.

Two examples will be used to illustrate typical program output. The first addresses the steady state thermomehcanical simulation of a radially loaded 40mm bore spherical roller bearing. The second shows typical output obtained when simulating planetary gear spherical roller bearing performance.

4.1 EXAMPLE 1: Simulation of Steady State Bearing Performance

SPHERBEAN was used to simulate steady state thermomechanical performance of the roller bearing test rig shown in Figure 18. The system incorporates a 40mm bore double row spherical roller bearing (Table 5), a dummy cylindrical roller bearing, hydrostatic radial and thrust bearings, shaft, housing and lubrication systems.[13]

The test rig and bearings are modelled by the 50 nodes shown in Figures 19 and 20 using the program's "Option 6". Nodal representations of pertinent rig components are identified in Table 6.

The output generated for Example 1 is presented in Appendix C. In this appendix, page 1 lists the user defined spherical bearing nodes and nodes where bearing heat is generated. Note that each source of bearing generated heat splits its output between two bearing components. For example, in row #1, heat generated at all roller (node 10) to outer race (node 12) contacts is evenly distributed: 50% to the rollers and 50% to the outer race.

Constant heat generation sources are also listed on output page 1. In this example, nodes 24 and 28 represent lip seals,

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[13] A complete description of the test rig can be found in Volume III of this report. [2].

and 6.7 watts were provided at each site to represent the sliding power loss. Nodes 32,33 and 44 were used to simulate power loss in the test rig slave bearing. The value of 180 watts (60 watts at each node) was computed using a handbook estimate of the slave bearing's power loss at 3000 rpm.

Pages 2 through 6 are an organized listing of the user specified special input data needed for system temperature calculations. This data completely defines the thermal simulation.

Page 7 displays the first system temperature map, and represents the initial common temperature of 93°C input on Card 2. Nodes 45 through 50 have fixed temperatures, and represent the system boundary conditions.

Page 8 lists options in effect during the program execution. Roller and ring geometry, as input by the user, is also listed.

Page 9 presents an organized listing of the user defined cage geometry, material properties and lubrication data. Surface geometry and applied loads are listed on page 10.

The bearing fatigue life, as well as individual L_{10} fatigue lives of the outer and inner rings, are presented on page 11. The bearing life represents the statistical combination of the two raceway lives. Raceway lives reflect the combined effects of:

(1) the user input material factors

(2) lubricant film thickness factors.

The film thickness to surface roughness ratio is used in the calculation of a life reduction factor. Detailed information for this calculation is given in [6] and [7].

(3) Life modification for material other than basic steel [1].

(4) Life modification for edge loading of rollers [1].

The lubricant data shown on page 12 is self-explanatory. Temperatures at which properties are evaluated correspond to the calculated steady state operating conditions.

Pages 13-14: The roller-raceway contact loads at the outer and inner ring contacts are defined in the $\bar{R}$ coordinate[14] frame, illustrated in Figure 21. These forces will include both elastic and lubricant traction effects for solution levels 2, 3, or 4. Rollers are numbered in ascending order beginning with the roller lying on the bearing y-axis and proceeding counter clockwise, Figure 4.

Page 15: The forces applied to the inner ring constitute system loading information specified by the user. Radial misalignment is included in the program output for future use. The calculated "inner ring reactive forces and moments" are the resultant of the vector sum of all roller-inner ring contacts.

[14] The $\bar{R}$ coordinate frame is fully defined in Volume I, Appendix A [1].

Load values are included with the output to assess the degree of convergence at the lower solution levels. In this LEVEL = 2 execution, the user specified applied load was 3000 lbs in the Y direction. The program arrived at a solution of:

$$Y = -2999 \text{ lbs}$$
$$Z = -87.98 \text{ lbs}$$

Note that the theoretically correct solution requires Z = 0 and the 87.98 lb Z directed residual represents 3% deviation from the applied load. If the user requires a "tighter" solution, SPHERBEAN must be executed at LEVEL = 3 or LEVEL = 4.

Page 16 lists the centrifugal force vectors and Z directed gyro-moments at each roller location in the bearing complement. If a planetary bearing is analyzed, these loads will include the effects of planetary motion. The coordinate system used is that shown in Figure 21.

Page 17 summarizes bearing heat generation rates. Hydrodynamic (HD) or "rolling" friction refers to the power loss created by churning the lubricant in the low pressure zone preceeding the Hertzian portion of the EHD roller to raceway contact. Bearing conductance is a measure of the resistance to heat flow across the bearing and is used in the computation of the steady state system temperatures.

Page 18: The Hertzian contact stresses represent <u>maximum</u>

values for the line (roller-raceway) contact. The lubricant film thicknesses represent minimum values for the line contact. EHD friction coefficient is computed by summing the absolute values of the EHD and HD loads at all slices, then dividing this value by the elastic (Hertzian) contact load.

Page 19 lists the starvation coefficient and meniscus distance at each roller location. In this version of SPHERBEAN, the starvation coefficient is not applied to the computed film thickness, and is included in the program output for the user's reference only. The meniscus distance is the distance from the contact center to the edge of the resevoir preceeding the Hertzian contact. This value is used in the computation of rolling (HD) friction power loss (see [1] for a more detailed description).

Page 20 displays the sliding velocity[15] distribution across the inner and outer ring contacts for roller number one. In this execution roller skew was not considered[16], therefore the x component of sliding is zero. Note that at the inner raceway, slice numbers 1, 2, 3, 18, 19 and 20 are not in contact with the inner race, and consequently all components of sliding velocity at these slices are printed as zero.

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[15] Sliding velocity refers to the difference in surface velocities at the point of contact between two slices.

[16] Skew is only considered at LEVEL = 3 or 4.

Page 21: Epicyclic cage speed is printed along with the calculated roller speeds for the user's reference. Epicyclic speeds are those speeds assumed by the bearing components in the absence of gross slip. These are useful in assessing roller skid. Roller rotational speed and roller orbital speed are computed in one of two ways. At solution levels one or two, the printed speeds are epicyclic. At levels three and four, the speeds are computed along with roller displacement independent variables.

Calculated roller skew and tilt is presented to the user in the roller reference frame ($\overline{R}$), and refers to the rotation the roller experiences relative to its initial position about its Y (skew) and Z (tilt) axis. Cage pocket loads presented on page 22 represent the loads experienced by the roller due to interaction with the cage web. In row 1, a negative sign indicates that that roller is pushing the cage. In row 2, a positive sign indicates the roller is pushing the cage.

Pocket loads are presented for solution levels 2, 3, or 4. At level two, pocket loads are estimated from rolling element Z equilibrium force equation residues. Pocket loads are computed such that rolling elements and cage are in equilibium, at levels three or four.

Page 23 lists cage rail and split cage data. Cage centrifugal load refers to the centrifugal force generated by carrier motion in a planetary bearing application.

Final operating temperatures of the bearing, as calculated under the temperature calculating program option, are shown for all nodes on page 24. These steady state temperatures are in degrees Celcius.

4.2 EXAMPLE 2: Planetary Bearing Analysis

SPHERBEAN output, when the program is used to simulate performance of a planetary gear bearing having a flexible outer ring, is similar to output obtained when analyzing mounted bearings. Three output pages which will be different are included in Appendix D.

Page 1 (which is the equivalent to page 10 in Appendix C) lists planet gear geometry, speed and load data. Note that in this example the carrier speed is assumed to be zero, and the radial component of gear tooth load has been (correctly) input with a negative sign. These valves are entered in Category (5).

Page 2 (equivalent to page 15 in Appendix C) details the applied and reactive inner ring loads. Note that the diametrally opposed tangent and moment tooth loads will cancel each other and produce no net load on the inner ring. The inner ring or "Post Load" will be the vector sum of tangent gear loads and the outer ring centrifugal load due to carrier rotation (which in this case is zero).

Page 3 is only printed when the planetary bearing analysis option is used, and lists the deflection of the outer ring at individual roller locations. The sign convention employed is positive outward.[17]

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[17] This sign convention is consistant with the one used for input of planet gear tooth radial load.

5.0 PROGRAM LIMITATIONS AND GUIDES TO PROGRAM USE

SPHERBEAN is a design tool, and as with any tool, successful use requires awareness of intended applicability and inherent limitations.

LIMITATIONS

The user must conform to the following geometric and operating restrictions:

(1) The bearing complement may contain no more than thirty rollers per row. However, in order to execute the program at levels 3 or 4 under combined load for double row bearings having more than 17 rollers per row, it is necessary to increase the size of the C array which stores partial derivatives. The array is currently dimensioned to accommodate a 144 X 144 array of partials [COMMON/LINCO/C(20740)].. In the event that the array size must be increased, the program prints out the error message given below indicating the required dimension size and execution is stopped.

```
NUMBER OF DERIVATIVES HAS EXCEEDED THE
   ALLOWABLE STORAGE OF 20740
SPHERBEAN NEEDS AT LEAST___ STORAGE LOCATIONS
   TO DO CALCULATIONS FOR YOU
DIMENSION LIMITS MUST BE INCREASED* * * * * *
   EXECUTION STOPS * * * * *
```

The /LINCO/ common appears in subroutines DERIVS, SIMQ, and WRITC. It is also necessary to change the value of MAXNZ in subroutine DERIVS to correspond to the required C array size.

(2) System thermal models may use no more than 100 nodes.

(3) The number of unique heat transfer coefficients is limited to:

- conduction 10
- free convection 10
- forced convection 10
- radiation 10
- mass transport 10

(4) The number of heat transfer links is limited to 500.

GUIDES TO PROGRAM USE

SPHERBEAN uses a modified Newton-Raphson iterative method to compute solution values to the governing field equation set. The hard coded (default) values for iteration loop control, contained in CATEGORY SOLVE, were selected to provide satisfactory program performance for a broad class of bearing problems. In special instances, where the problem addressed is particularly complicated or bearing performance is being checked at an operating extreme the default parameters may be inadequate to provide a satisfactory solution. In this instance, the user may choose to override the default values. The following guidelines are meant to assist the user in defining when and what corrective action could be taken:

1. No corrective action need be taken if the diagnostic message shown in Table 7-A is printed. The message simply indicates that a problem was encountered during the solution procedure, but was self-corrected.
2. If the error message in Table 7-A is followed by 7-B, this indicates that the desired solution

accuracy has not been achieved and results are not printed.[18] The user can take the following corrective action:

- Simplify the problem - Ex.: If CAGDOF = 3, set CAGDOF = 1.
- Note the value for CURRENT NORM. If it is "close" to the value printed for REQUIRED NORM, the user may input a value of "TOL"[19] which equals 1/2 the value printed for the CURRENT NORM. An upper limit of TOL = .05 is suggested.
- Try a lower solution level. If LEVEL = 3 or 4, change to LEVEL = 2.

---

[18] In some instances the tolerance (NORM) is very close to the desired value when the message is printed. If the current norm is within 100% of the user specified requirement when no further improvement could be made, the program will continue the execution.

[19] See CATEGORY SOLVE.

6.0 LIST OF REFERENCES

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CATEGORY NUMBER	CATEGORY NAME	CATEGORY DESCRIPTION	INPUT DATA NECESSARY
1	LOGIC	PROGRAM LOGIC	NO
2	SOLVE	SOLUTION CONTROL DATA	NO
3	ROLLR	ROLLER GEOMETRY	YES
4	RNGEO	RING GEOMETRY/LOADS	YES
5	GEAR	PLANET GEAR DATA	NO
6	CAGE	CAGE DESCRIPTION	YES
7	LUBE	LUBRICANT DATA	NO
8	TEMPS	TEMPERATURES	NO
9	LIFE	FATIGUE COMPUTATION DATA	NO

TABLE 1

ORGANIZATION OF INPUT DATA CATEGORIES

CATEGORY NAME	VARIABLE NAME	TYPE[1]	DEFAULT VALUE	CATEGORY NAME	VARIABLE NAME	TYPE[1]	DEFAULT VALUE
LOGIC	FLGIF	L	.FALSE.	RNGEO	GROR	R	0.
	PLTROL	L	.FALSE.		GRIR	R	0.
	ECHO	L	.FALSE.		DCL	R	0.
	SPLTCG	L	.FALSE.		ALPHA	R	0.
	PLANET	L	.FALSE.		SPDIR	R	0.
	METRIC	L	.FALSE.		FLGANG	R	0.
	FITS	L	.FALSE.		FX	R	0.
	MPROP	L	.FALSE.		FY	R	0.
	SYMY	L	.TRUE.		FZ	R	0.
	EVSLIC	L	.TRUE.				
	THERM	L	.FALSE.	GEAR	NMESH	I	1
					TANGLE	R	0.
SOLVE	TOL	R	.05		SPDCAR	R	0.
	NITS	I	20		SPDR1	R	0.
	LEVEL	I	1		RCAR	R	0.
	PRINT	L	.FALSE.		XI	R	0.
	CAGDOF	I	1		RNVET	R	0.
					R1	R	0.
ROLLR	NS	I	5		R2	R	0.
	HRD	R	---		R3	R	0.
	ELO	R	---		T1	R	0.
	EL1	R	---		T2	R	0.
	FLENTH	R	---		T3	R	0.
	RCC	R	---		XM1	R	0.
	KLUCRN	I	2		XM2	R	0.
	PHI1	R	0.		XM3	R	0.
	PHI2	R	0.		DENS	R	.00775 kg/cm^3 (.2816 lb/in^3)
	NUMROL	I	---				
	REND	R	0.		XMASS	R	0.
	RSREX1	R	0.		E	R	204,083 N/mm^2 (29,500,000 lb/in^2)
	RSREX2	R	0.				
	ENDFLY	R	0.				

[1] TYPE REFERS TO VARIABLE TYPE, I.E., R = REAL VARIABLE, EXAMPLE: TOL = .05
I = INTEGER VARIABLE, EXAMPLE: NITS = 20
L = LOGICAL VARIABLE, EXAMPLE: FITS = .FALSE.

TABLE 2

DEFAULT VALUES FOR USER UNSPECIFIED VARIABLES

CATEGORY NAME	VARIABLE NAME	TYPE[1]	DEFAULT VALUE	CATEGORY NAME	VARIABLE NAME	TYPE[1]	DEFAULT VALUE
CAGE	ITYPE	I	0 (ROLLER RIDING)	TEMPS	RING11	R	100°C(212°F)
	RADCLR	R	0.		RING12	R	100°C(212°F)
	AXCLR	R	0.		RING21	R	100°C(212°F)
	WFBT	R	0.		RING22	R	100°C(212°F)
	NRAILS	I	1		BULK	R	100°C(212°F)
	A	R	0.		FLG1	R	100°C(212°F)
	B	R	0.		FLG2	R	100°C(212°F)
	XMU	R	.07		SHAFT	R	100°C(212°F)
	RAILD	R	0.		HOUSE	R	100°C(212°F)
	RAILW	R	0.		ROLL1	R	100°C(212°F)
	RCLR	R	0.		ROLL2	R	100°C(212°F)
					RACE11	R	100°C(212°F)
LUBE	NCODE	I	4 (MIL-L-23699)		RACE12	R	100°C(212°F)
					RACE21	R	100°C(212°F)
	ZTO	R	5.08×10^{-4}mm (2×10^{-7}in)		RACE22	R	100°C(212°F)
					CAGE1	R	100°C(212°F)
	ZTI	R	5.08×10^{-4}mm (2×10^{-7}in)		CAGE2	R	100°C(212°F)
	ZTFL	R	5.08×10^{-4}mm (2×10^{-7}in)	LIFE	RMSROL	R	.2 MICRONS (8×10^{-6}in)
	FRK	R	.07		RMSIR	R	.25 MICRONS ($10.\times10^{-6}$in)
	AKN	R	18.2		RMSOR	R	.25 MICRONS ($10.\times10^{-6}$in)
	XMURC	R	.075		RMSFL	R	.25 MICRONS ($10.\times10^{-6}$in)
	XMUFL	R	.075		RMSRE	R	.25 MICRONS ($10.\times10^{-6}$in)
	XMUCG	R	.075		CIR	R	1.
	XCAV	R	1.		COR	R	1.

[1] TYPE REFERS TO VARIABLE TYPE, I.E., R = REAL VARIABLE, EXAMPLE: TOL = .05
I = INTEGER VARIABLE, EXAMPLE: NITS = 20
L = LOGICAL VARIABLE, EXAMPLE: FITS = .FALSE.

TABLE 2 (CONTINUED)

DEFAULT VALUES FOR USER UNSPECIFIED VARIABLES

TABLE 3

PROPERTIES OF FOUR LUBRICANTS

LUBRICANT NUMBER (NCODE)	LUBRICANT TYPE	KINEMATIC VISCOSITY (CS) 37.78°C (100°F) (VIS100)	KINEMATIC VISCOSITY (CS) 98.89°C (210°F) (VIS210)	DENSITY @15.56°C (60°F) gm/cm³ (RHO60)	THERMAL CONDUCTIVITY W/m/°C (COND)	THERMAL COEFF. OF EXPANSION 1/°C 10^{-3} (G)	FILM THICKNESS COEFF. AKN
1	Mineral Oil	64.0	8.0	0.88	0.116	6.336	18.2
2	MIL-L-7808G	17.8	3.2	0.95	0.152	7.092	18.2
3	Polyphenal Ether	25.4	4.13	1.20	0.119	7.470	24.9
4	MIL-L-23699	28.0	5.1	1.01	0.152	7.452	18.2

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SEQUENCE	PROGRAM OPTION	LOGIC USED TO INVOKE OPTION	INPUT CARD FORMAT (SEE FIGURE BELOW IN APPENDIX A)
1	PERFORM FIT CALCULATIONS	FITS = .TRUE.	A1
2	USER INPUT MATERIAL PROPERTIES	MPROP = .TRUE.	A2
3	USER INPUT OF SLICE WIDTHS	SYMY = .TRUE. AND EVSLIC = .FALSE.	A3
4	USER INPUT OF SYMMETRIC ROLLER GEOMETRY	SYMY = .TRUE. AND KLUCRN = 3	A4
5	USER INPUT OF ALL ROLLER GEOMETRY	SYMY = .FALSE. AND KLUCRN = 4	A5
6	TEMPERATURE CALCULATIONS (STEADY STATE OR TIME TRANSIENT)	THERM = .TRUE.	A6

TABLE 4

ORGANIZATION OF SPECIAL INPUT DATA

Rings:

Outer Ring Groove Radius	1.5898	in.
Inner Ring Groove Radius	1.6923	in.
Operating Diametral Clearance	.002	in
Contact Angle	14.17	DEG
Inner Ring Speed	3000	RPM
Inner Ring Load	3000	LBS

Rollers:

Diameter	.5122	in.
Crown Radius	1.574	in.
End Sphere Radius	5.552	in.
Effective Length	.469	in.
Number of Rows	2	
Number of Rollers Per Row	12	

Cage:

Pocket Radial Clearance	.01	in.
Pocket Axial Clearance	0	in.
Pocket Web Thickness	.137	in.
(Roller Riding Single Piece Cage)		

TABLE 5

SPECIFICATIONS OF SPHERICAL ROLLER BEARING USED IN EXAMPLE 1

NODE NUMBER	DESCRIPTION
4	SHAFT
6	SPHERICAL BEARING - INNER RING ROW #1
7	SPHERICAL BEARING - INNER RING ROW #2
8	SPHERICAL BEARING - CAGE ROW #1
9	SPHERICAL BEARING - CAGE ROW #2
10	SPHERICAL BEARING - ROLLERS ROW #1
11	SPHERICAL BEARING - ROLLERS ROW #2
12	SPHERICAL BEARING - OUTER RING ROW #1
13	SPHERICAL BEARING - OUTER RING ROW #2
14	HOUSING
19	COMPARTMENT AIR
22	COMPARTMENT AIR
24	LABYRINTH SEAL #1
28	LABYRINTH SEAL #2
32	DUMMY CYLINDRICAL BEARING - ROLLERS
33	DUMMY CYLINDRICAL BEARING - INNER RING
36	LUBRICANT IN DUMMY CYLINDRICAL BEARING CAVITY
38	LUBRICANT IN SPHERICAL BEARING CAVITY
44	DUMMY CYLINDRICAL BEARING - OUTER RING
45	LUBRICANT ENTERING SPHERICAL TEST BEARING
46	LUBRICANT ENTERING THRUST HYDROSTATIC BEARING
48	LUBRICANT ENTERING RADIAL HYDROSTATIC BEARING
49	LUBRICANT IN RESERVOIR
50	LUBRICANT ENTERING DUMMY CYLINDRICAL BEARING

TABLE 6

DICTIONARY OF NODES USED IN SYSTEM MODEL, EXAMPLE 1

ERROR MESSAGE FROM EQUATION SOLVING ROUTINE
ALGORITHM NO. ____, LOOP = ____
DIVERGED ITERATION - TOTAL NUMBER OF DIVERGED
ITERATIONS = ____.

A) DIVERGENCE MESSAGE

ERROR MESSAGE FROM EQUATION SOLVER
LOOP = ____, ALGORITHM = ____,
REQUIRED NORM[20] = ____
CURRENT NORM = ____

CURRENT NORM IS NOT WITHIN 100% OF USER SPECIFIED
REQUIREMENT AND NO FURTHER IMPROVEMENT CAN BE MADE,
EXECUTION STOPS

B) ABORT MESSAGE

TABLE 7: TWO DIAGNOSTIC MESSAGES GENERATED IN THE NEWTON-RAPHSON EQUATION SOLVER

---

[20]Required Norm is the user input value "TOL"

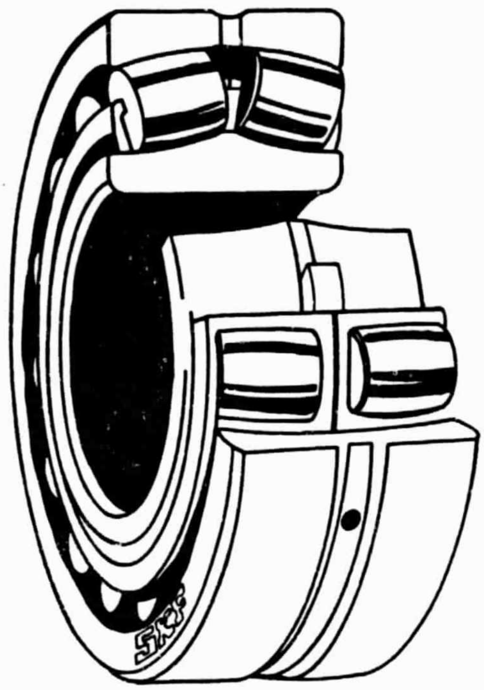


FIGURE 1 - SPHERICAL ROLLER BEARING

FIGURE 2: USE OF FREE FORMAT TO SPECIFY INPUT DATA.

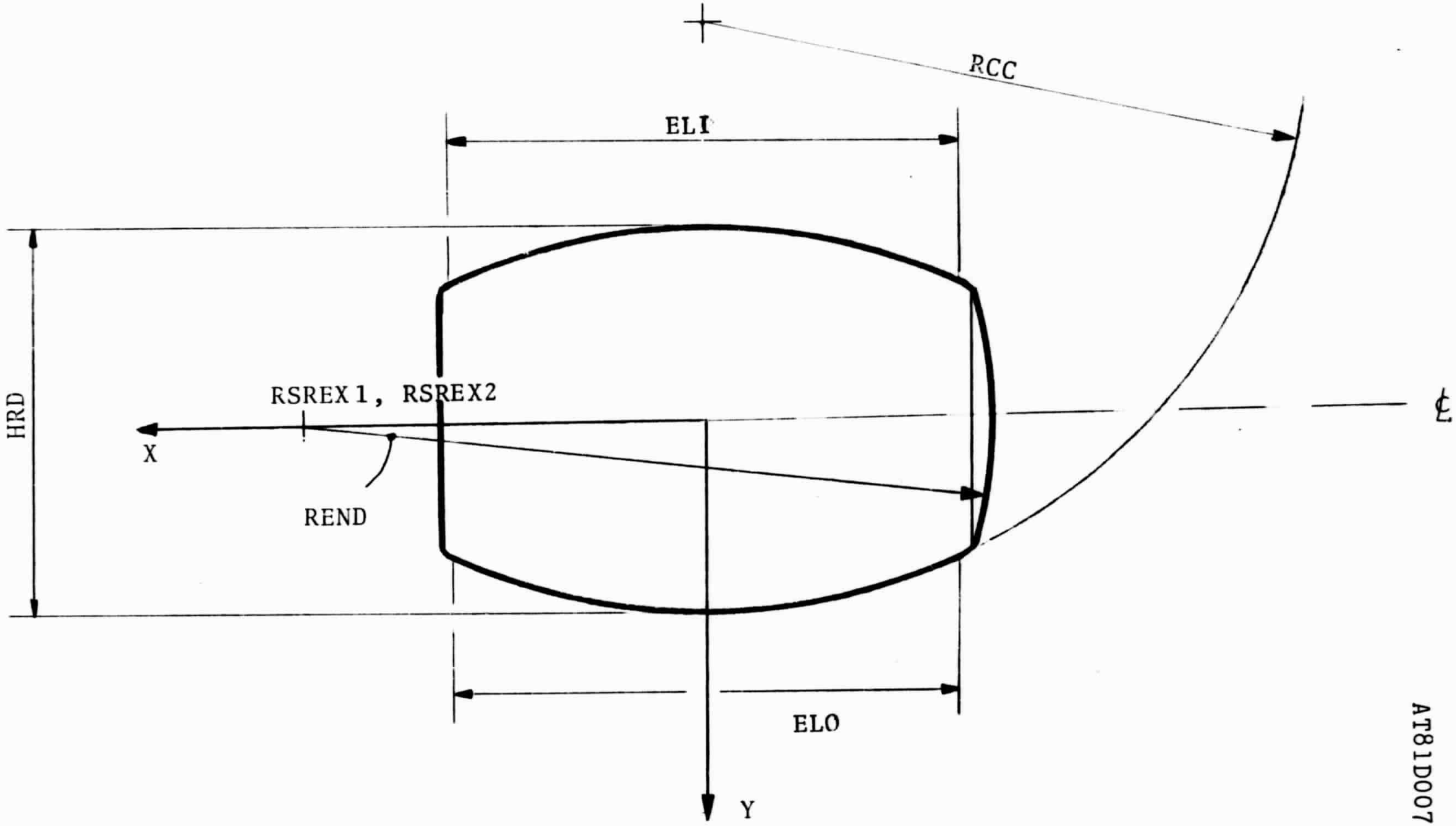
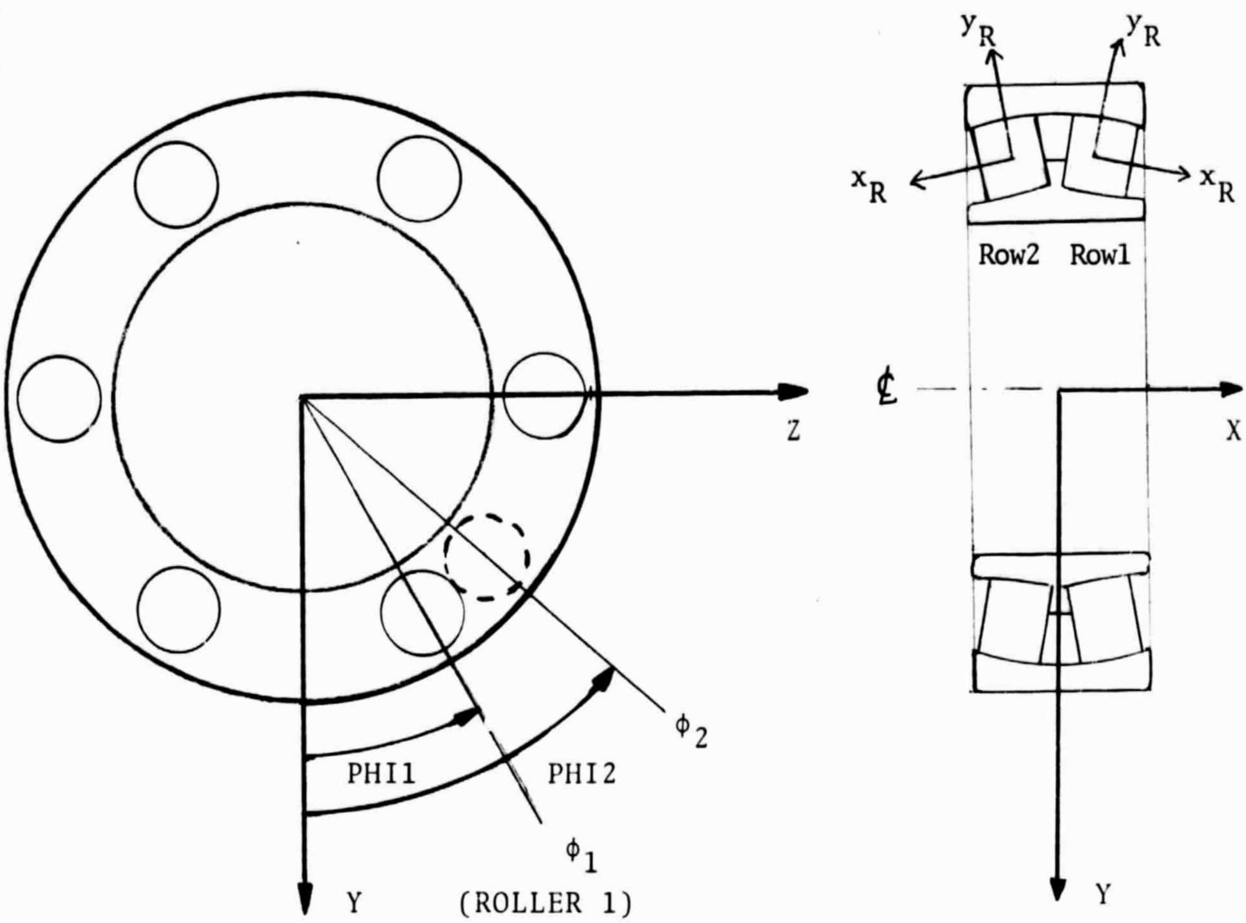


FIGURE 3: USER INPUT ROLLER GEOMETRY.



NOTE: PHI1 REFERS TO FIRST ROLLER IN ROW #1
PHI2 REFERS TO FIRST ROLLER IN ROW #2 (SHOWN DOTTED)

FIGURE 4: BEARING COORDINATE FRAME.

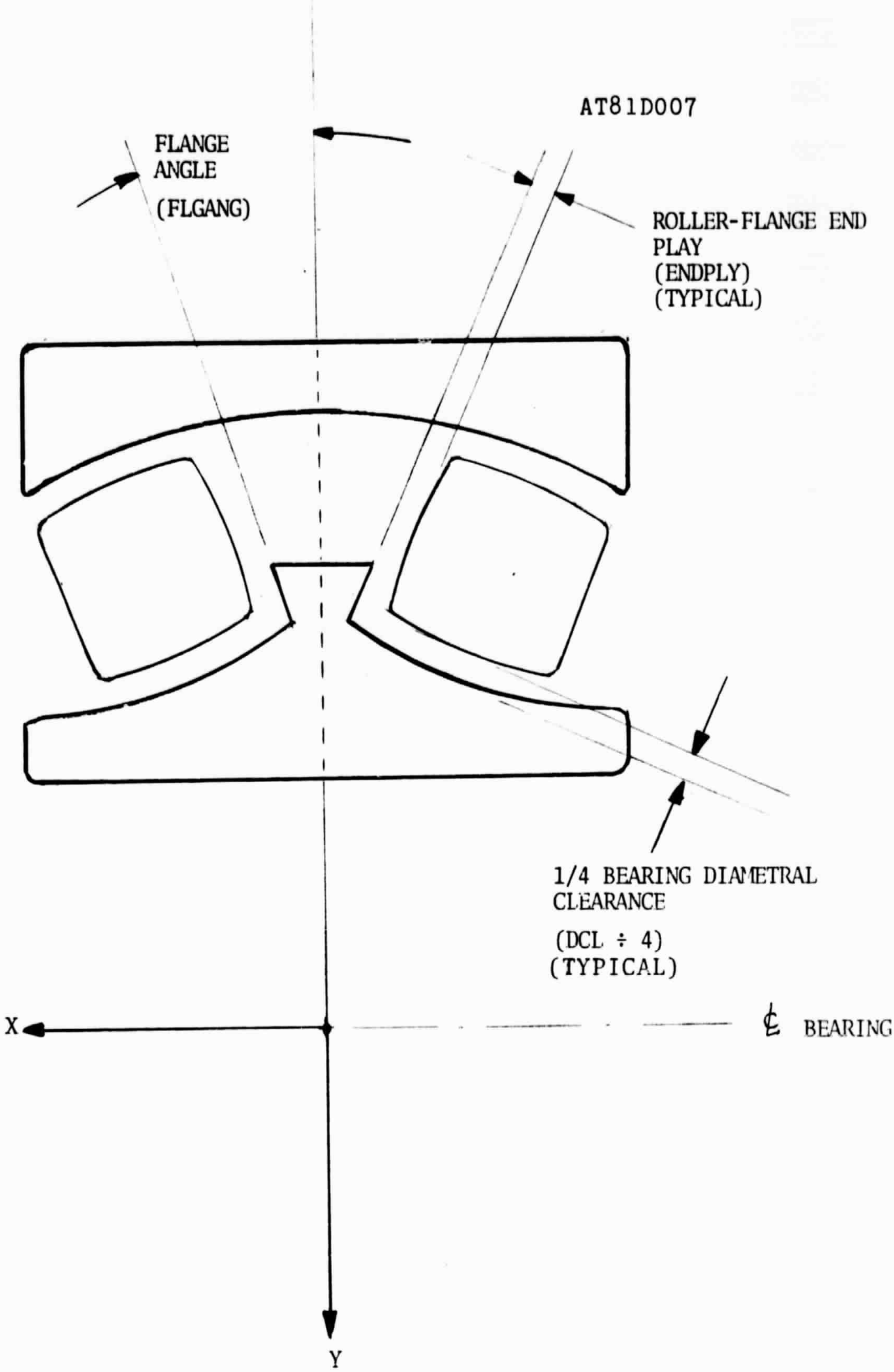


FIGURE 5: USER INPUT BEARING CLEARANCES.

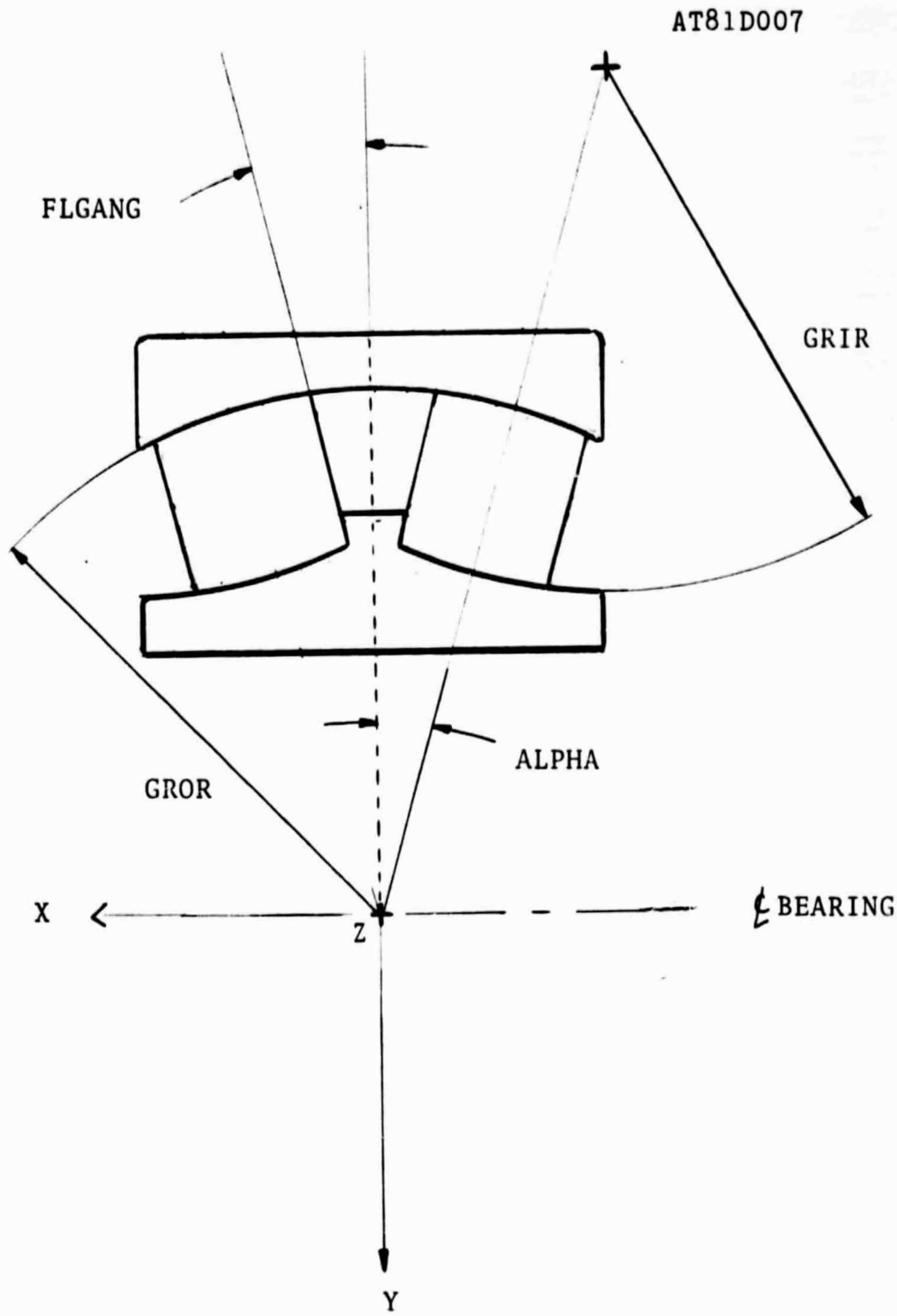


FIGURE 6: USER INPUT RING DATA.

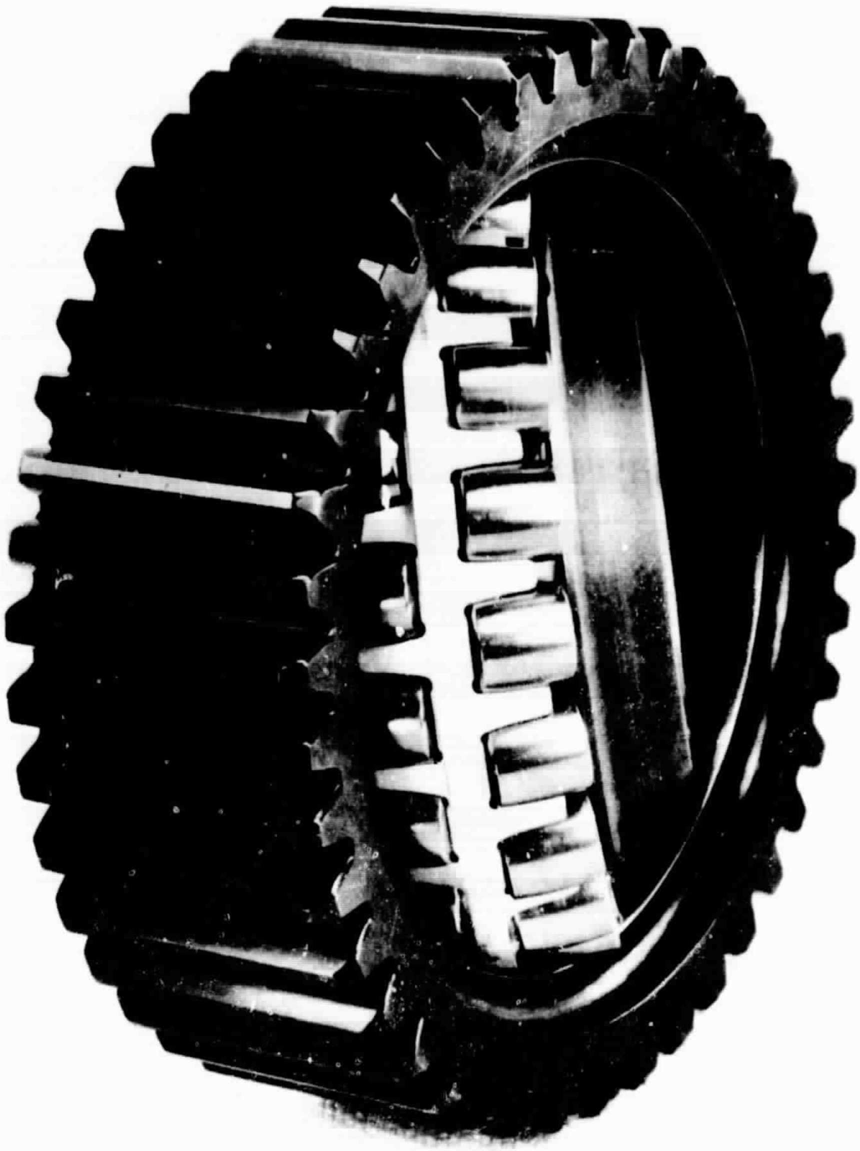


FIGURE 7: PLANET BEARING

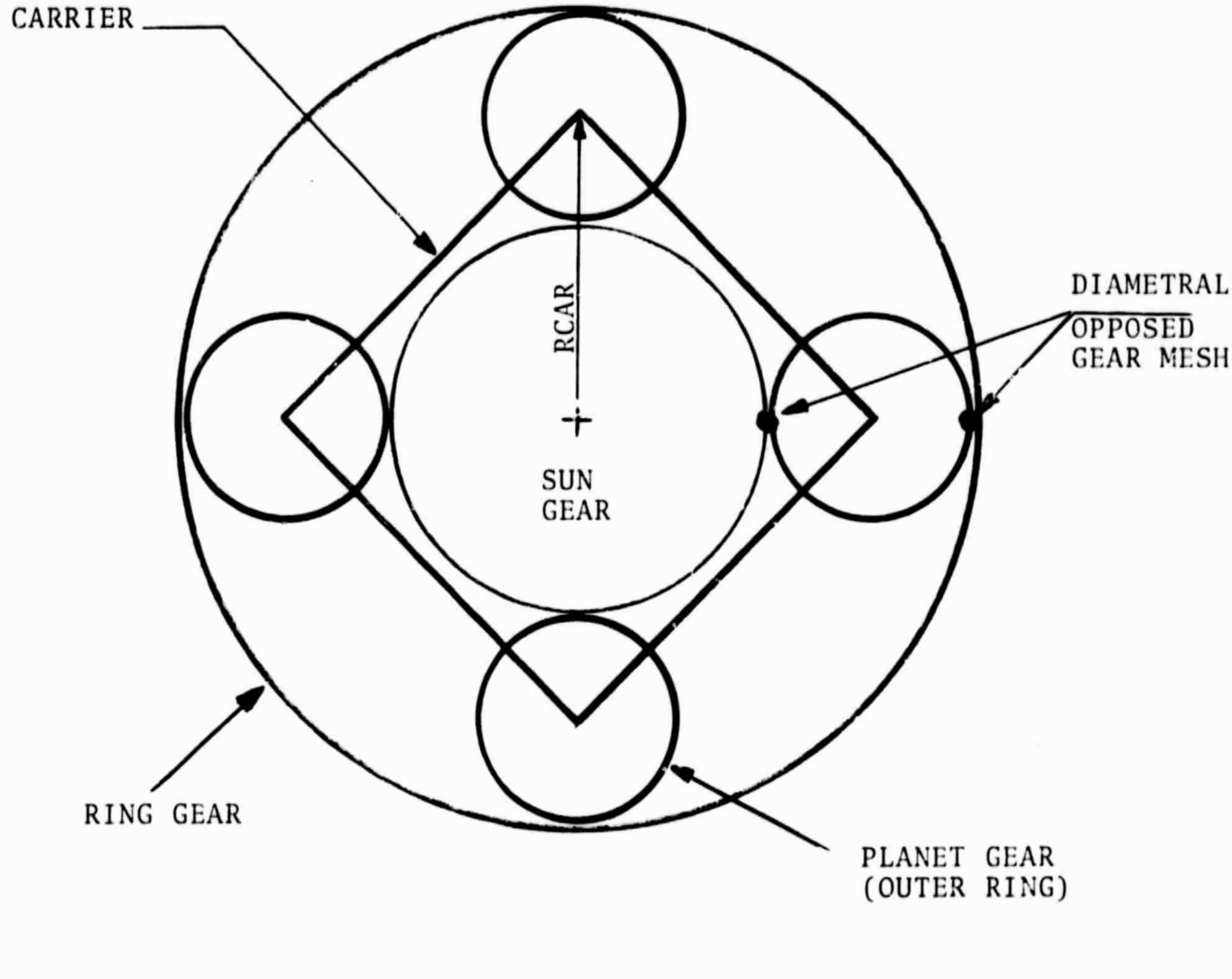


FIGURE 8: PLANETARY TRANSMISSION.

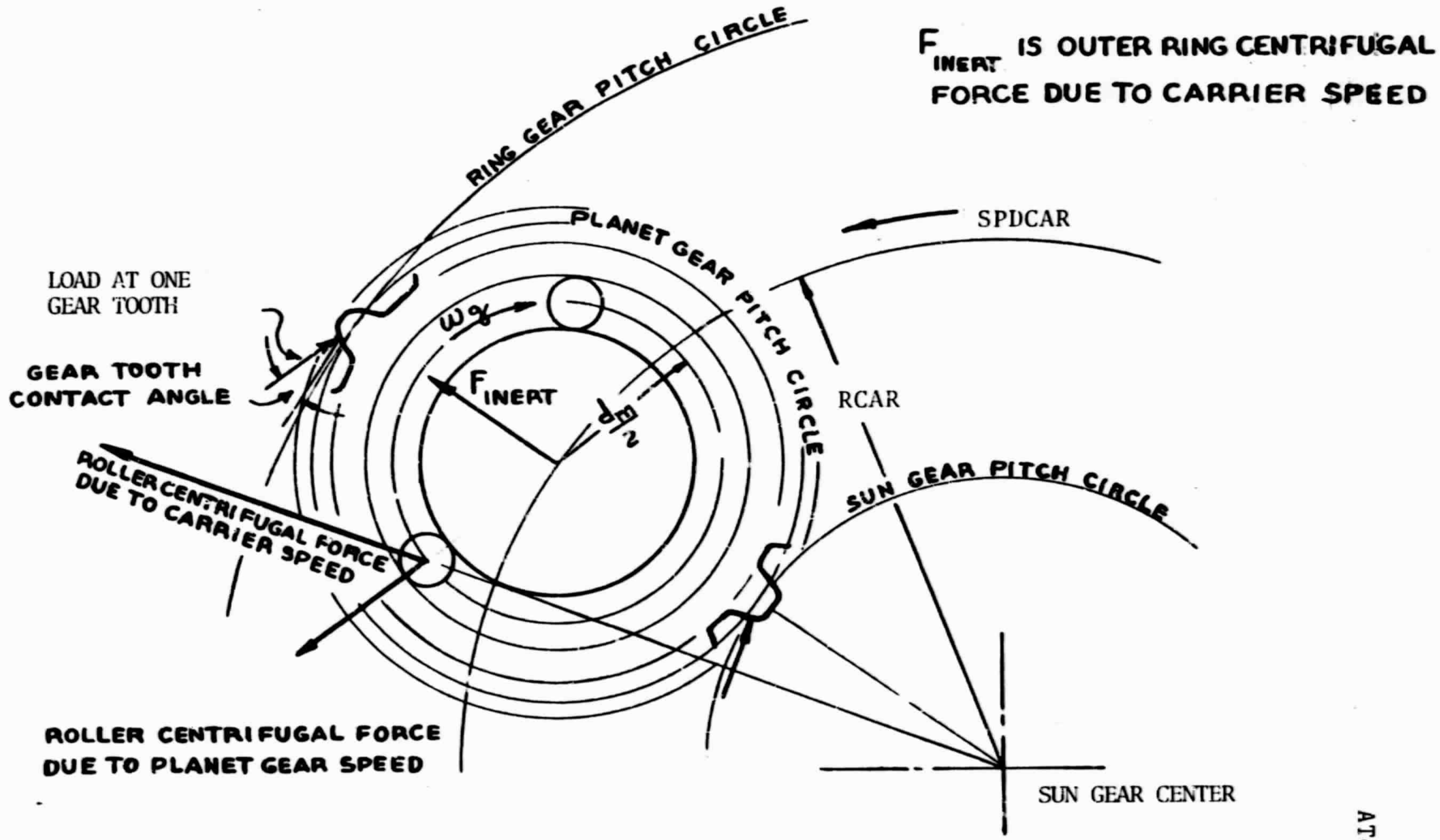


FIGURE 9: HIGH SPEED PLANET GEAR LOADING.

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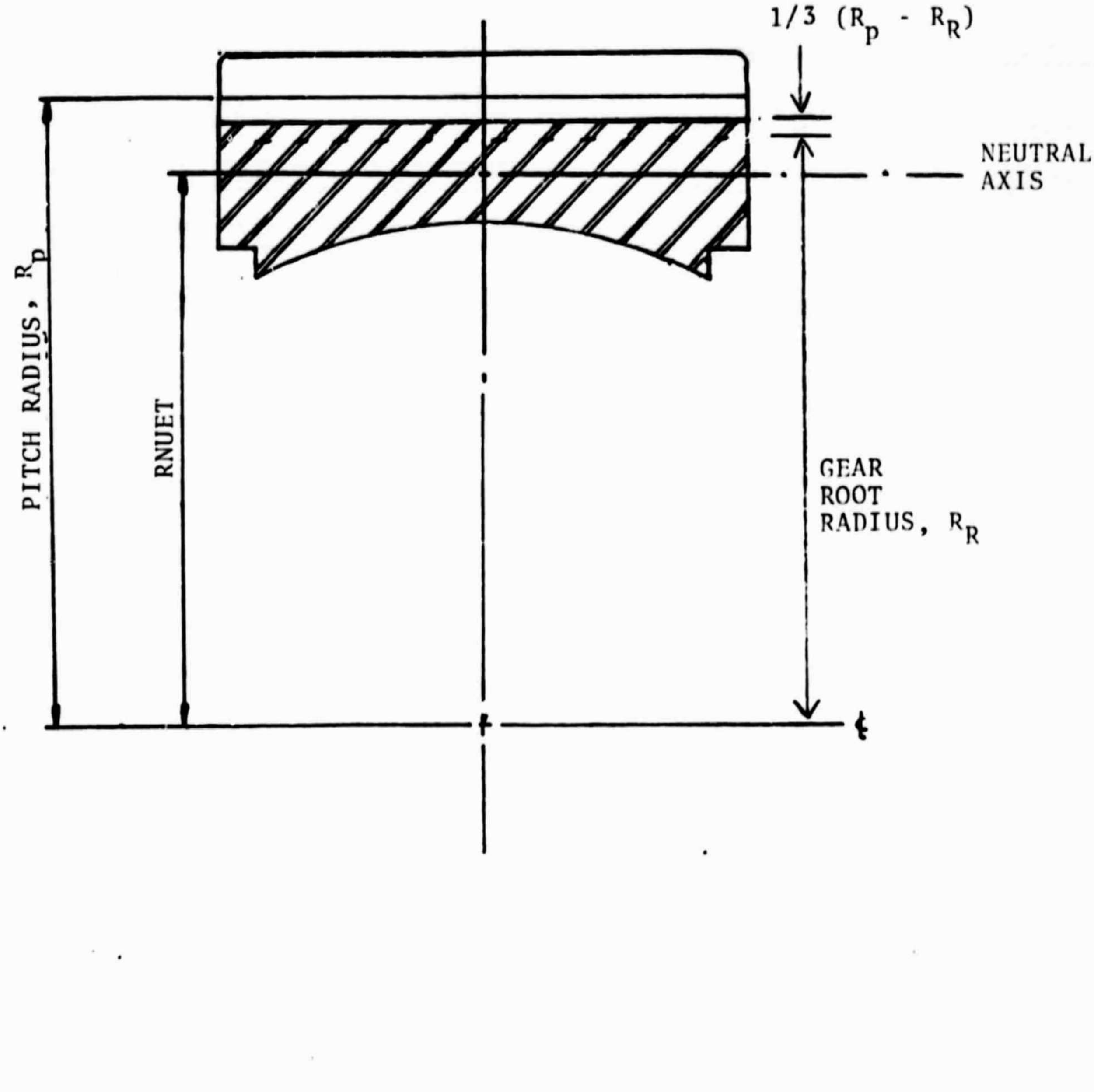


FIGURE 10: PLANET GEAR OUTER RING CROSS-SECTION (Effective area for computation of XI shown cross-hatched.)

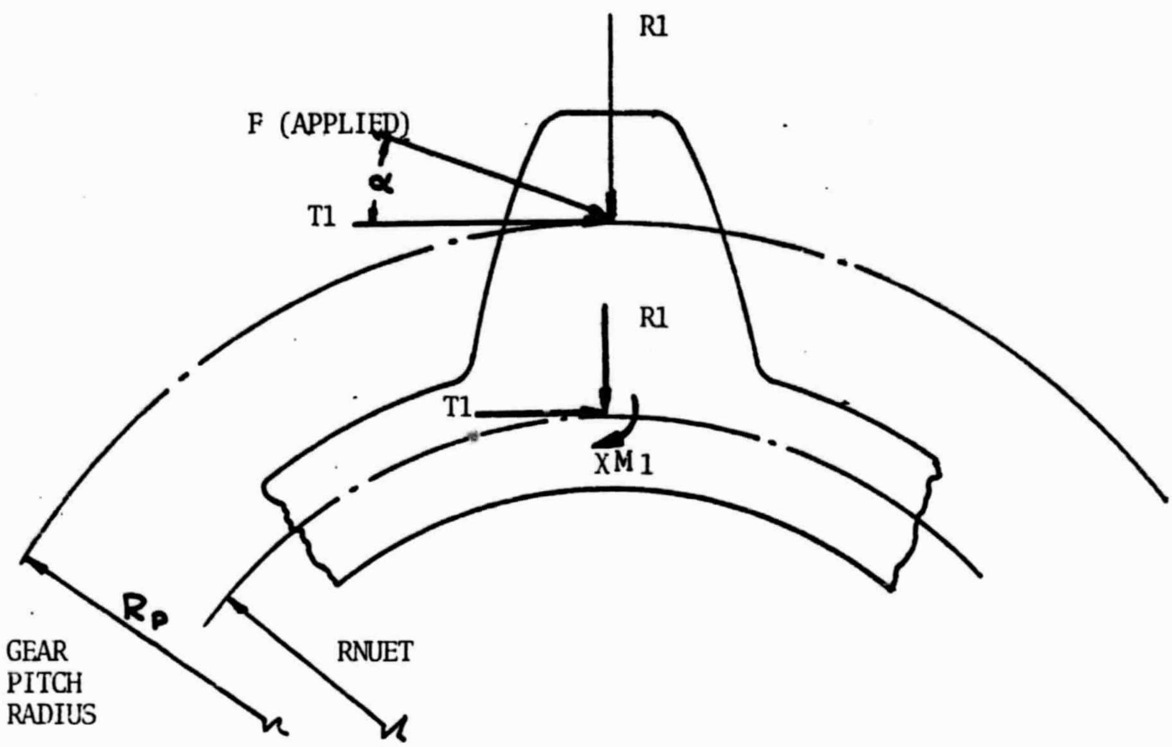


FIGURE 11: IDEALIZED GEAR TOOTH LOADS.

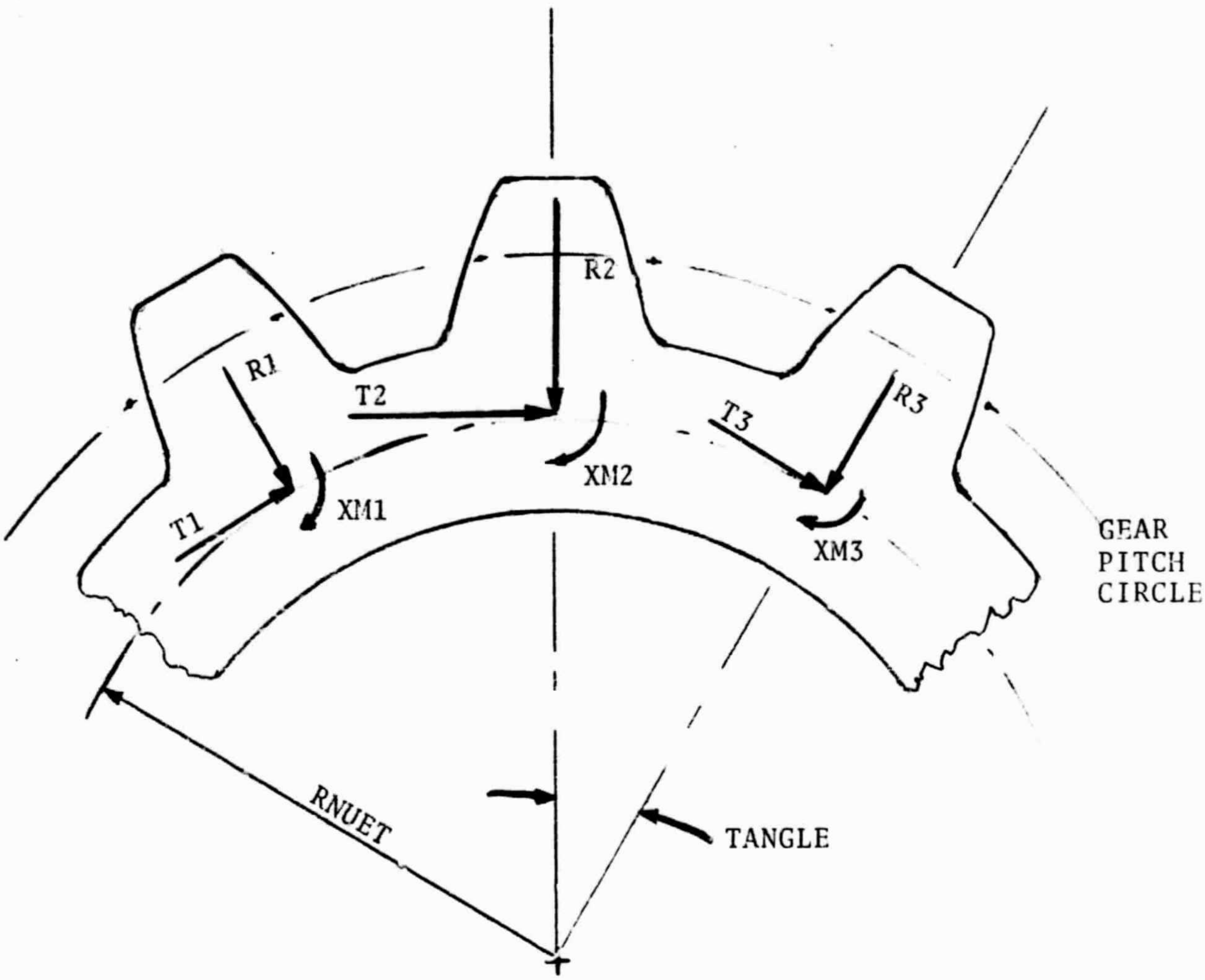
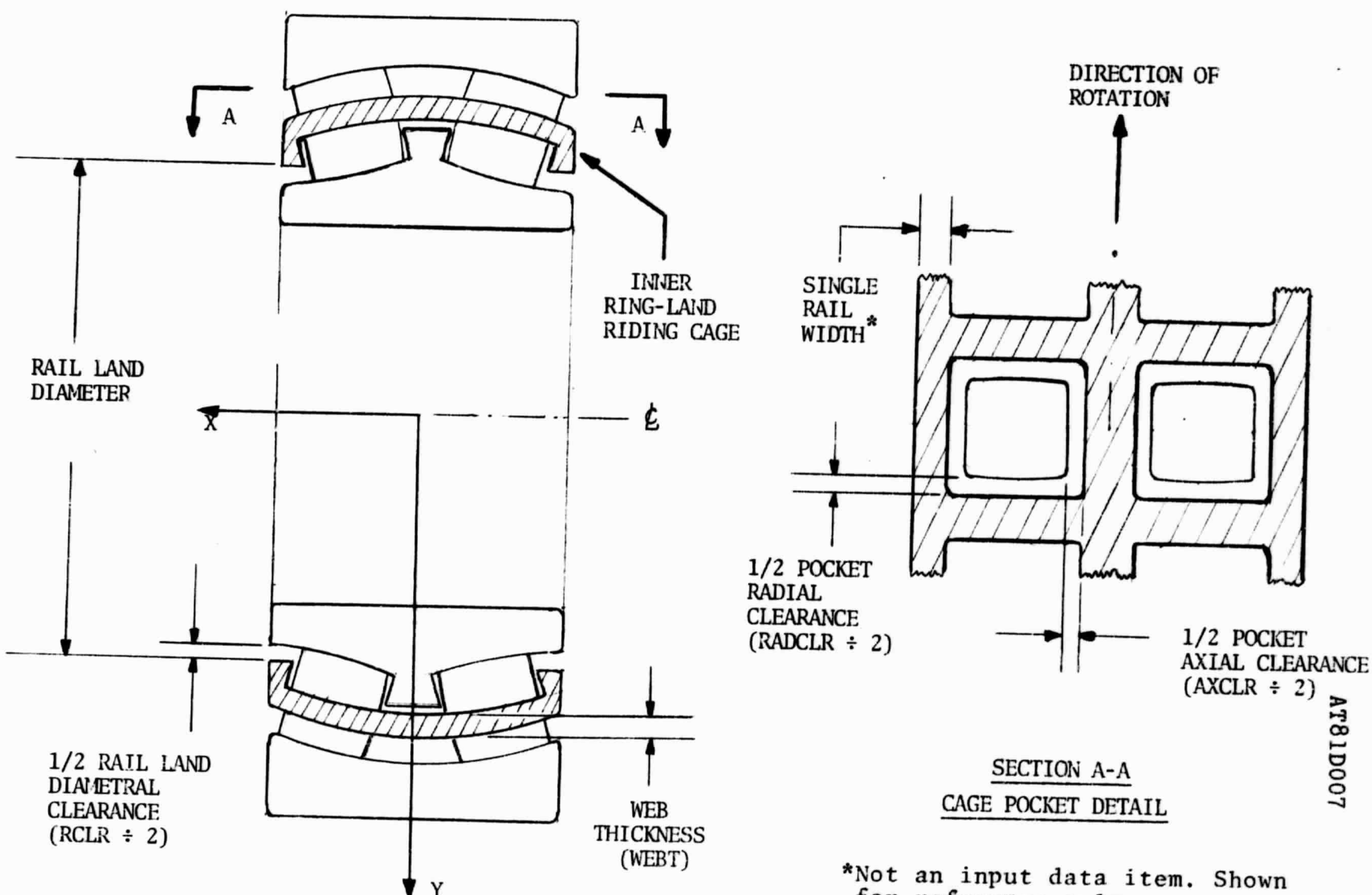
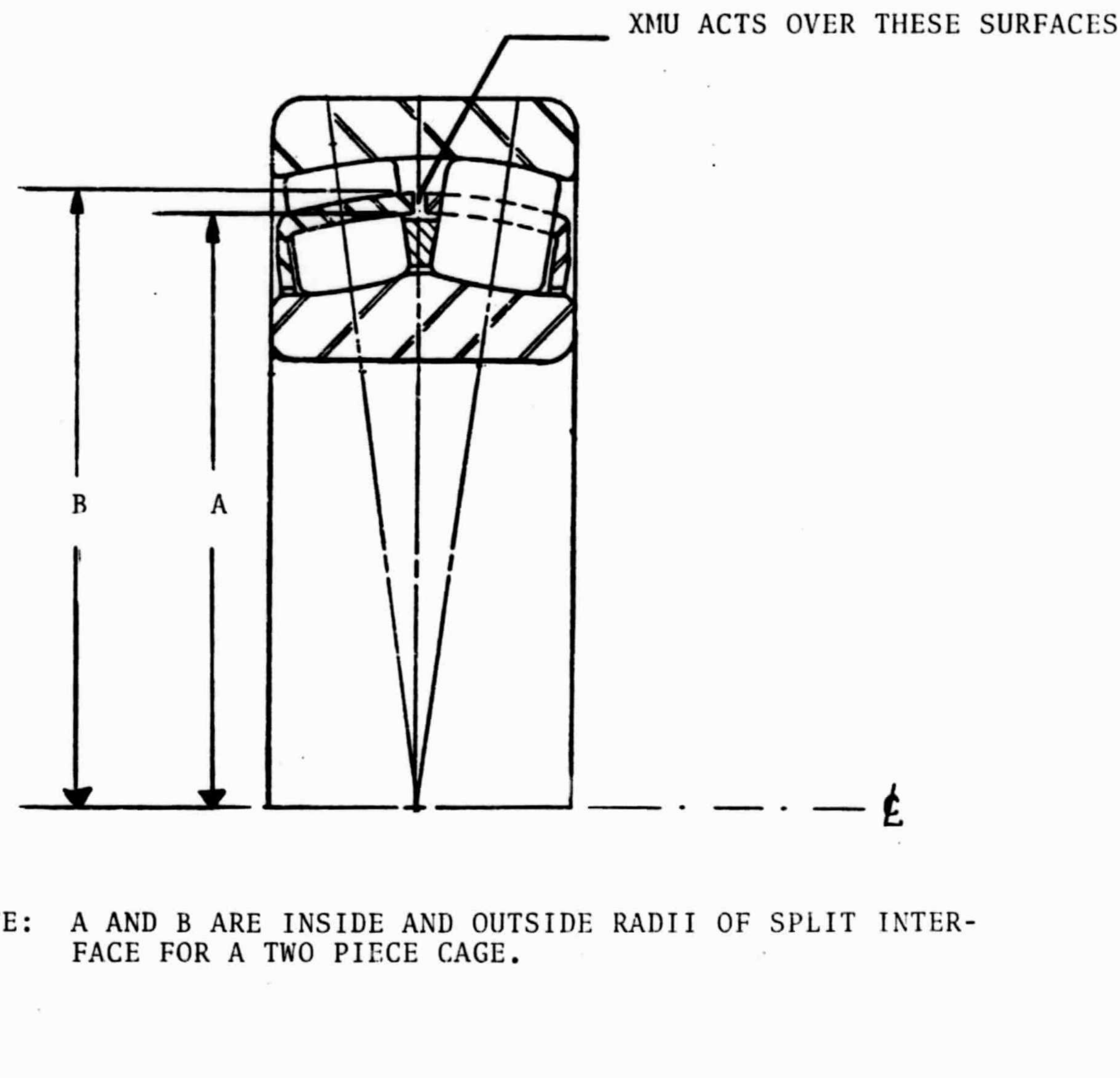


FIGURE 12: TOOTH LOADS ON PLANET GEAR
(NMESH = 3)



*Not an input data item. Shown for reference only.

FIGURE 13: CAGE GEOMETRY.



NOTE: A AND B ARE INSIDE AND OUTSIDE RADII OF SPLIT INTERFACE FOR A TWO PIECE CAGE.

FIGURE 14: SPLIT CAGE INPUT DATA.

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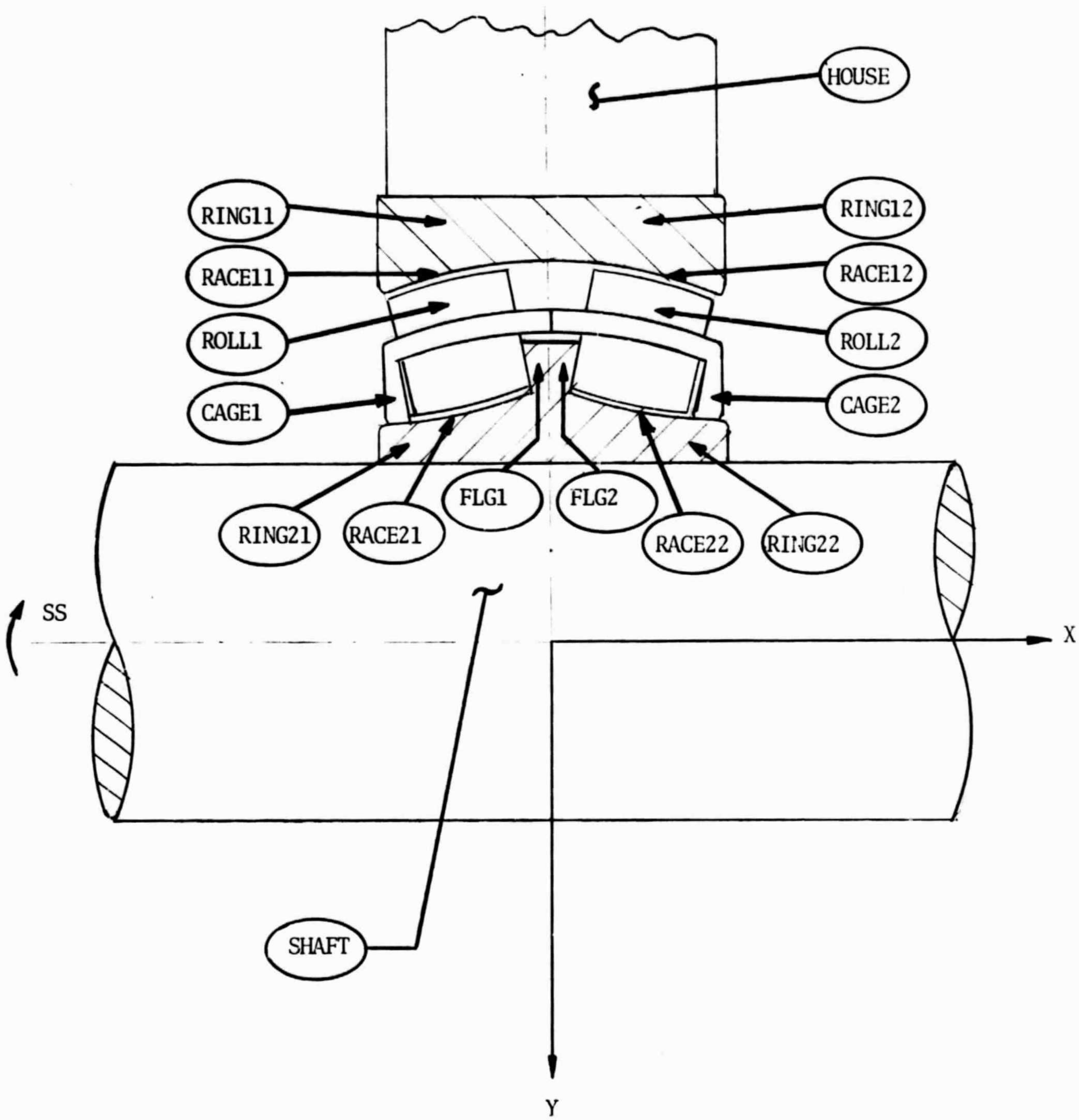
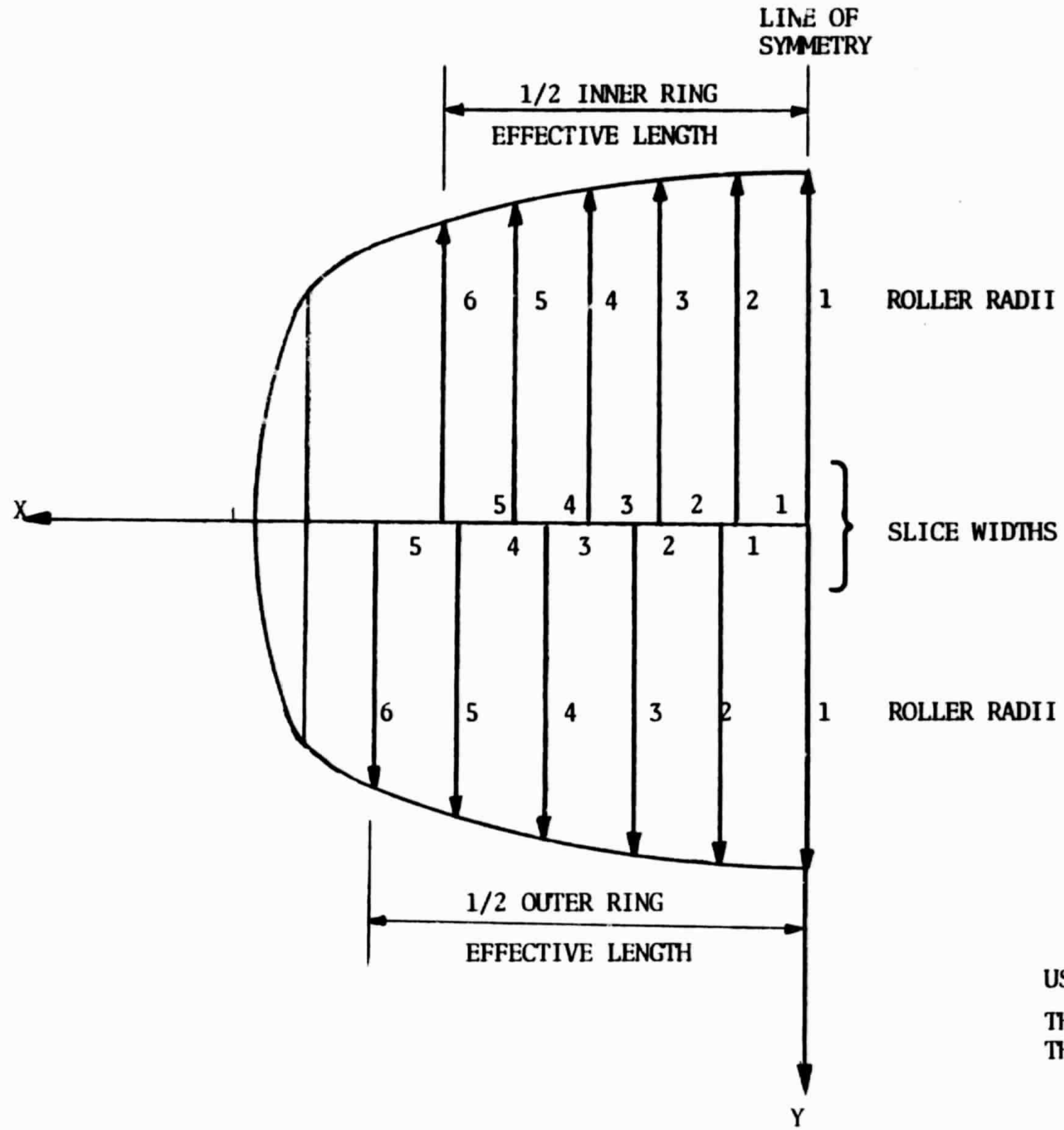


FIGURE 15: TEMPERATURE NODE IDENTIFICATION SCHEME.



USER NOTE:

THE NUMBER OF RADII EQUALS
THE NUMBER OF SLICES PLUS ONE.

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FIGURE 16: OPTIONAL SYMMETRIC ROLLER GEOMETRY INPUT DATA.

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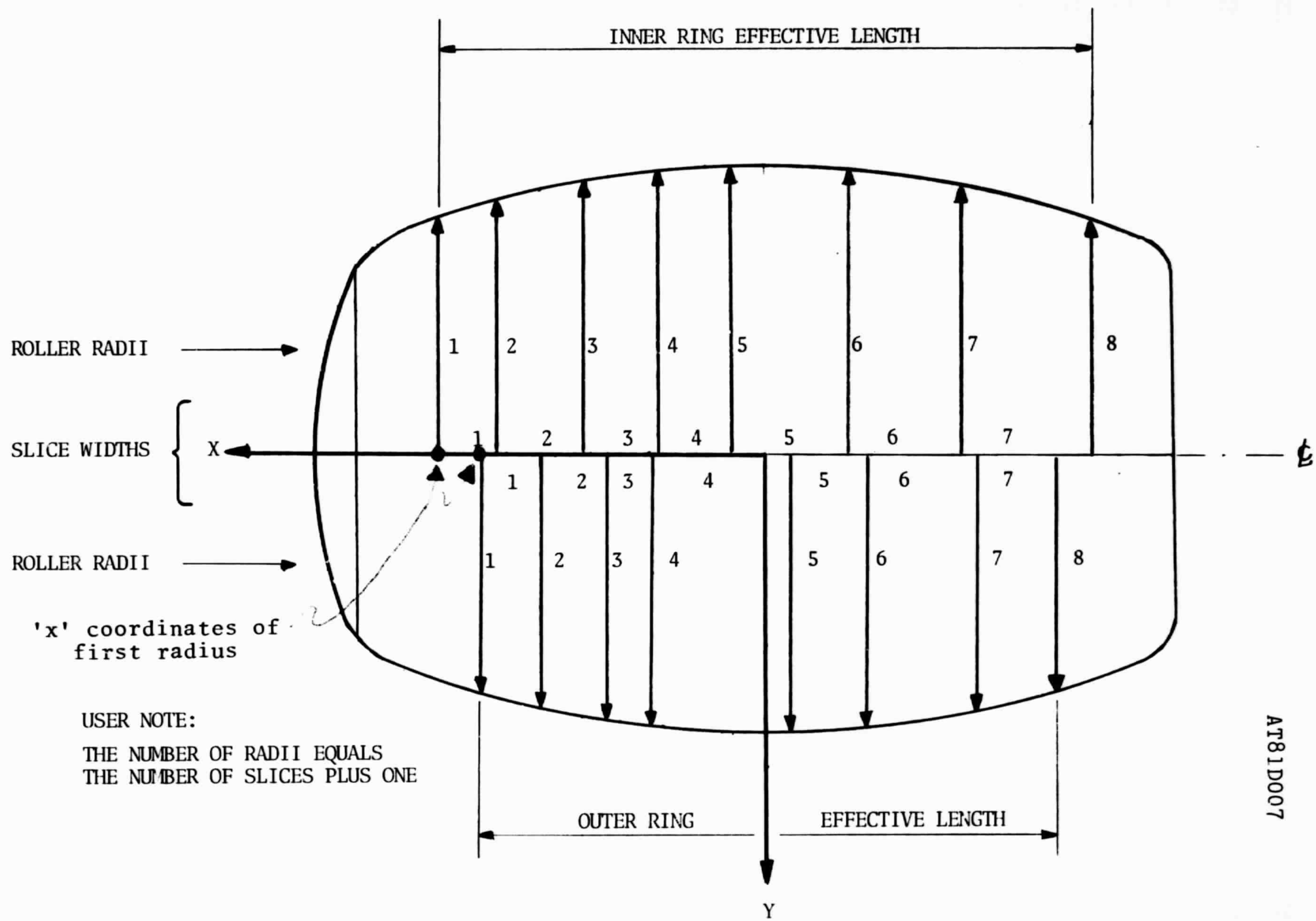

FIGURE 17: OPTIONAL ROLLER GEOMETRY DATA.

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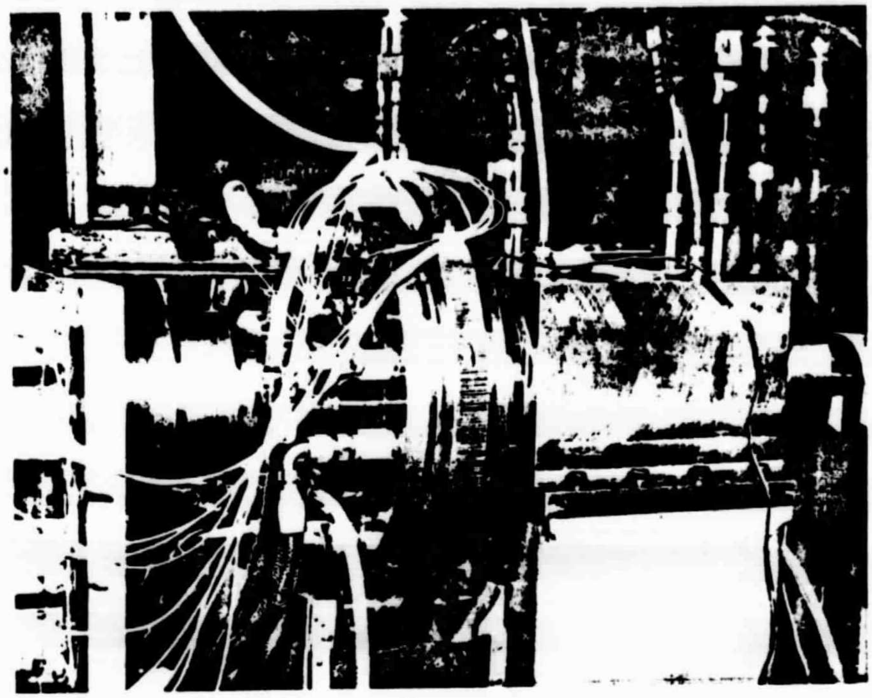

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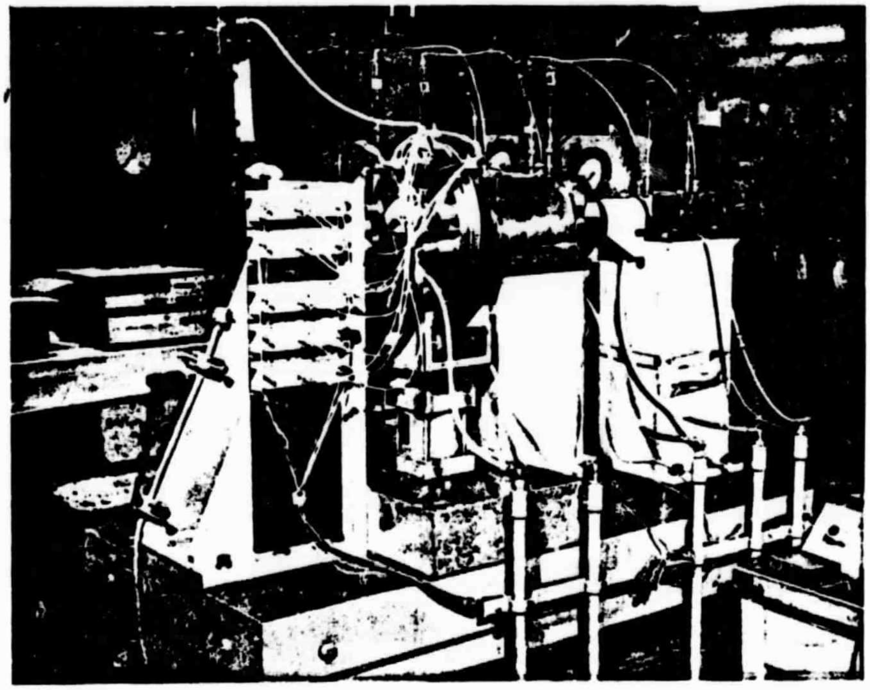

FIGURE 18: SPHERICAL ROLLER BEARING TEST RIG

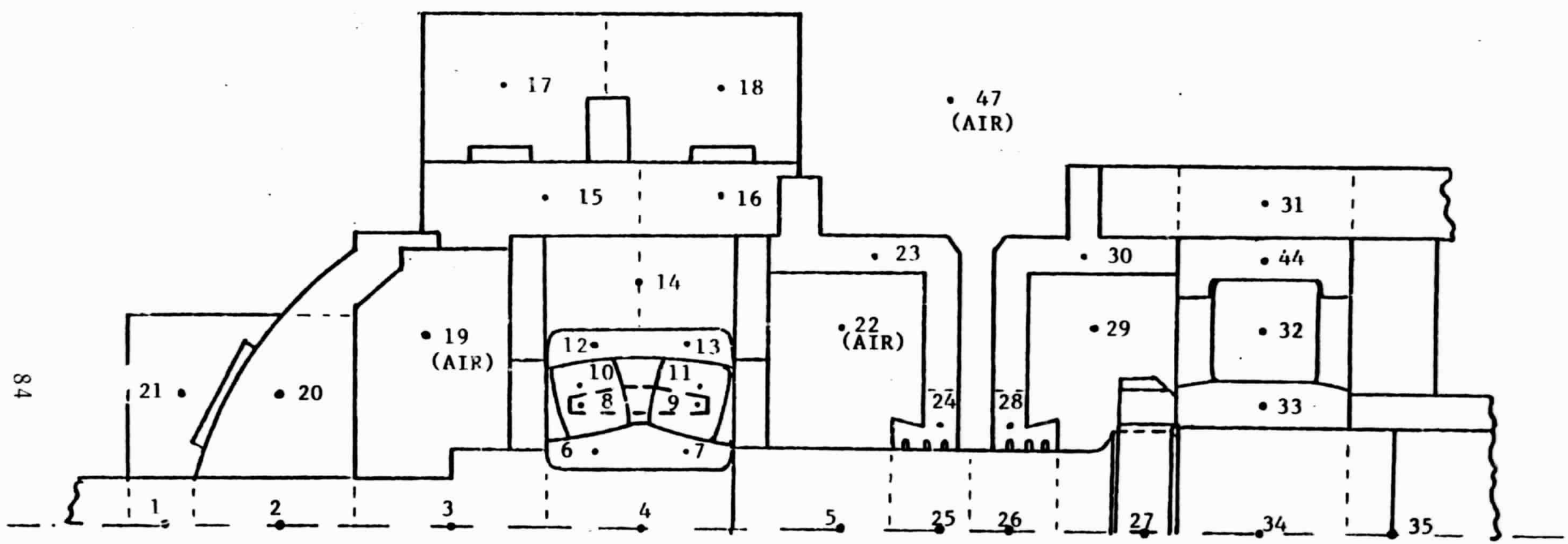

FIGURE 19 : SYSTEM MODEL USED IN EXAMPLE 1.
(METAL AND AIR NODES)

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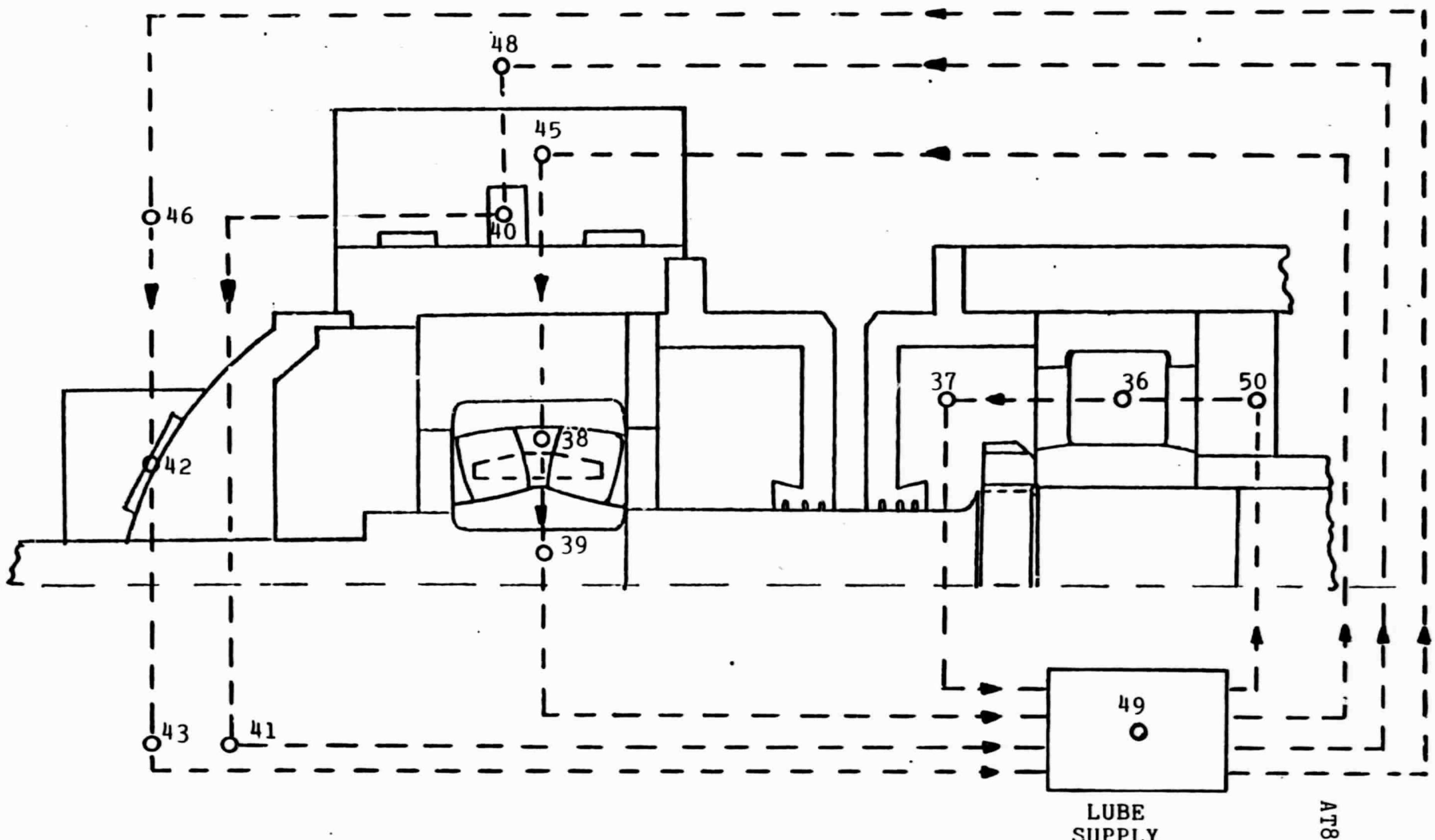

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FIGURE 20 : SYSTEM MODEL USED IN EXAMPLE 1,
(LUBRICANT SYSTEM NODES)

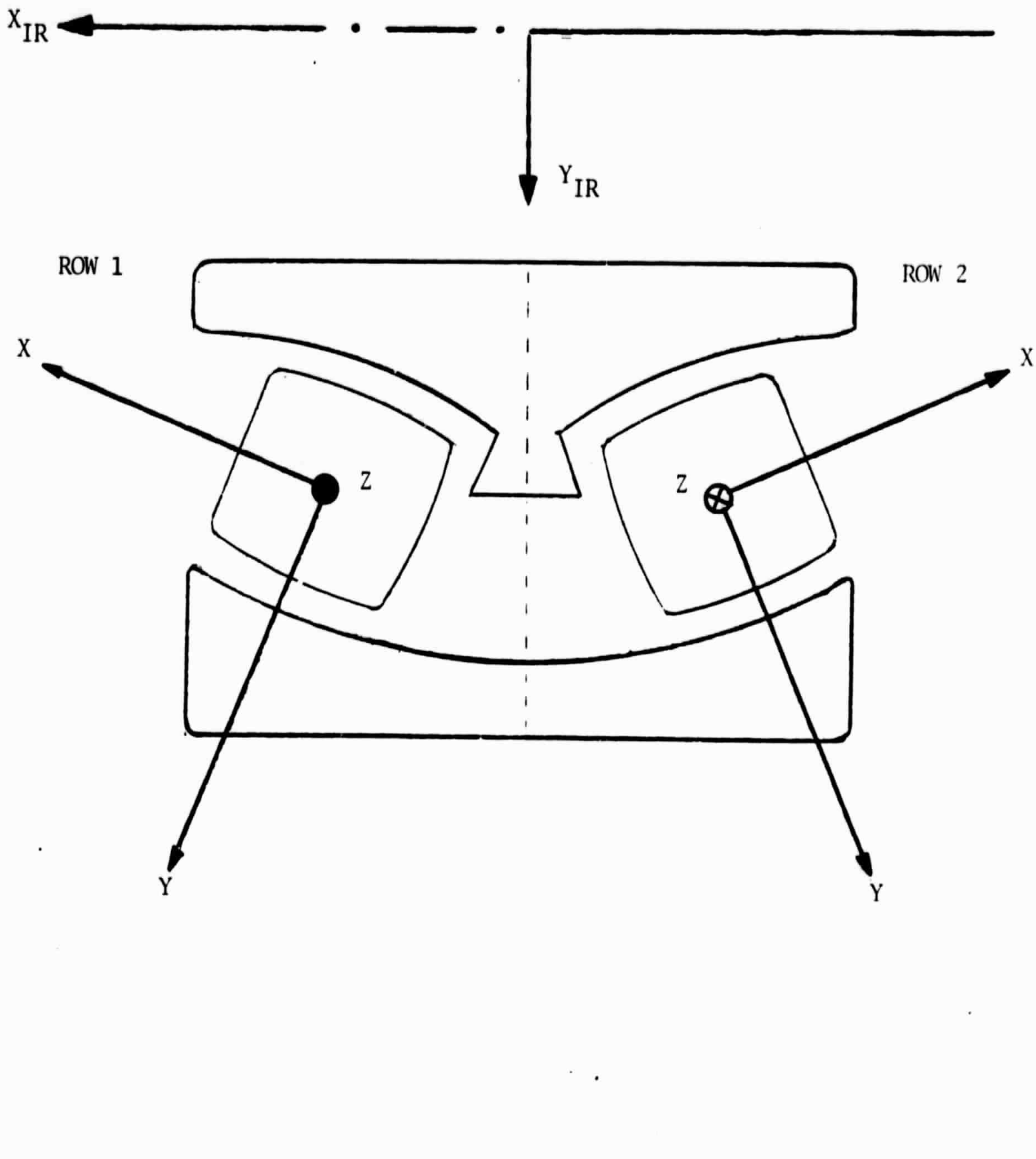

FIGURE 21: ROLLER COORDINATE FRAMES USED IN PROGRAM OUTPUT.

APPENDIX A:

SPECIAL INPUT DATA CARD FORMATS

FIG. A1: USER INPUT DATA FOR COMPUTATION OF BEARING OPERATING CLEARANCE (OPTION 1)

CARD 1

Columns 1–10	Columns 11–20	Columns 21–30	Columns 31–40	Columns 41–50	Columns 51–60	Columns 61–80
F10.0	F10.0	F10.0	F10.0	F10.0	F10.0	
SHAFT/INNER RING INTERFERENCE OR CLEARANCE	HOUSING/OUTER RING INTERFERENCE OR CLEARANCE	SHAFT EFFECTIVE WIDTH W_S	INNER RING EFFECTIVE WIDTH W_I	OUTER RING EFFECTIVE WIDTH W_O	HOUSING EFFECTIVE WIDTH W_H	

CARD 2

Columns 1–10	Columns 11–20	Columns 21–30	Columns 31–40	Columns 41–50	Columns 51–60	Columns 61–80
SHAFT INSIDE RADIUS a	INNER RING BORE RADIUS b	INNER RACEWAY RADIUS c	OUTER RACEWAY RADIUS e	OUTER RING OUTSIDE RADIUS f	HOUSING OUTSIDE RADIUS g	

NOTES: 1. Effective widths account for the greater radial rigidity of a shaft than the ring pressed on to it, owing to the fact that the shaft deflects over a length that extends beyond the ring width. Calculated internal pressure on the ring, due to its fit on the shaft, is distributed over the shaft effective width and this (lower) pressure is used in computing shaft deflection. Using double the actual width as the effective width is customary.

2. Input interference is measured on the radius; a positive number indicates interference, a negative number indicates clearance.

3. The user may specify data in inches (METRIC = .FALSE.) or millimeters (METRIC = .TRUE).

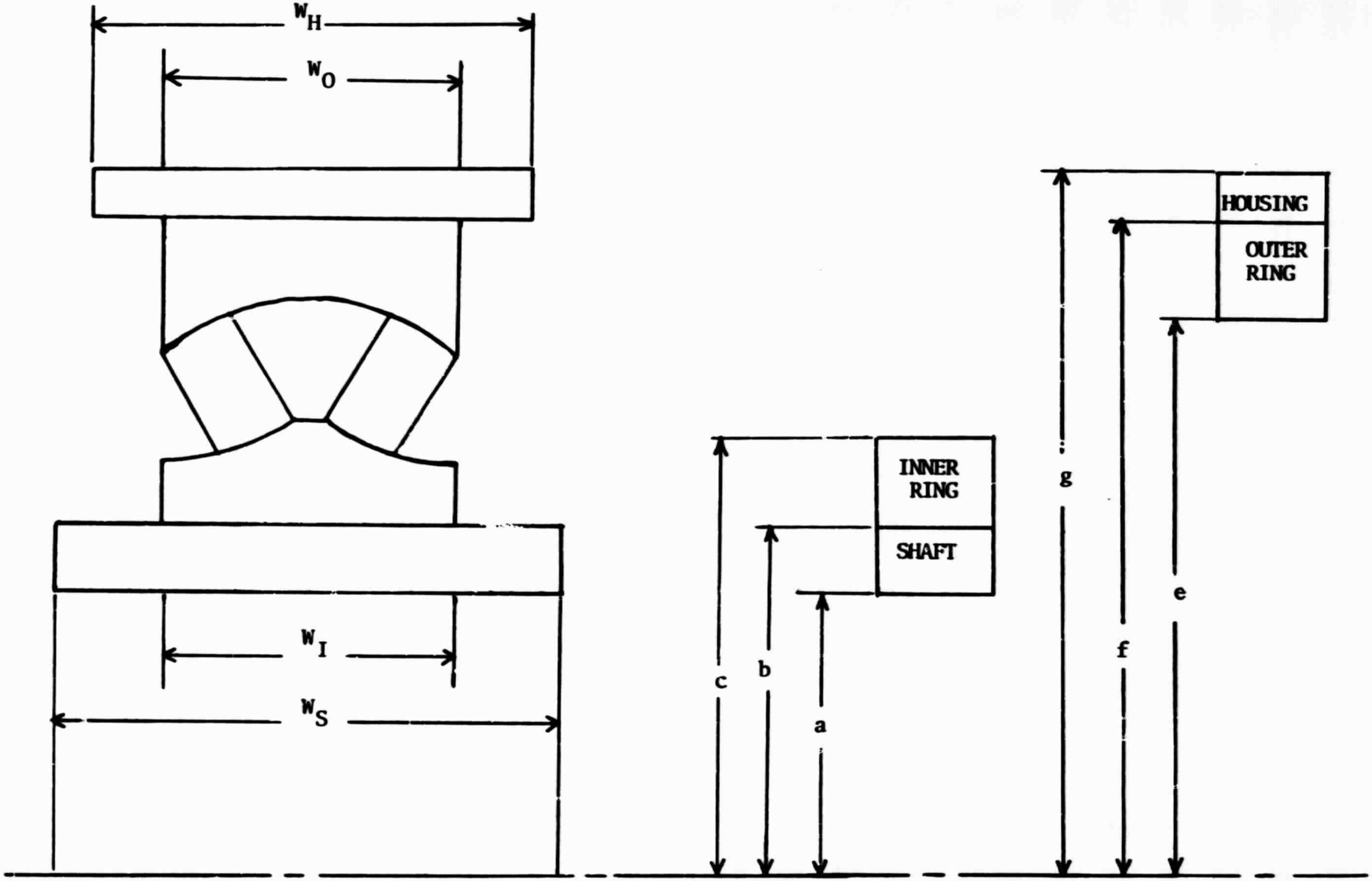

FIGURE A1A: INPUT DATA DEFINITIONS FOR BEARING OPERATING CLEARANCE CALCULATION

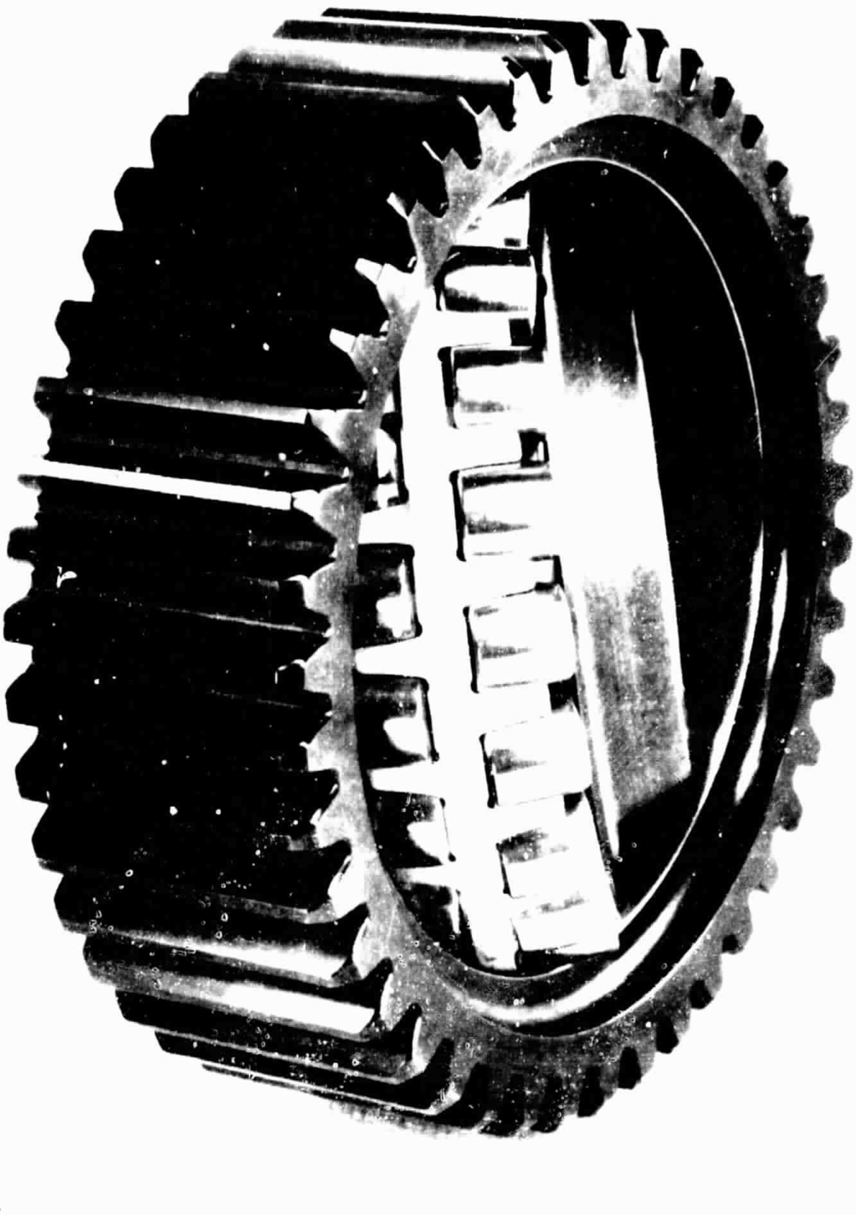

FIGURE [illegible]: PLANET BEARING

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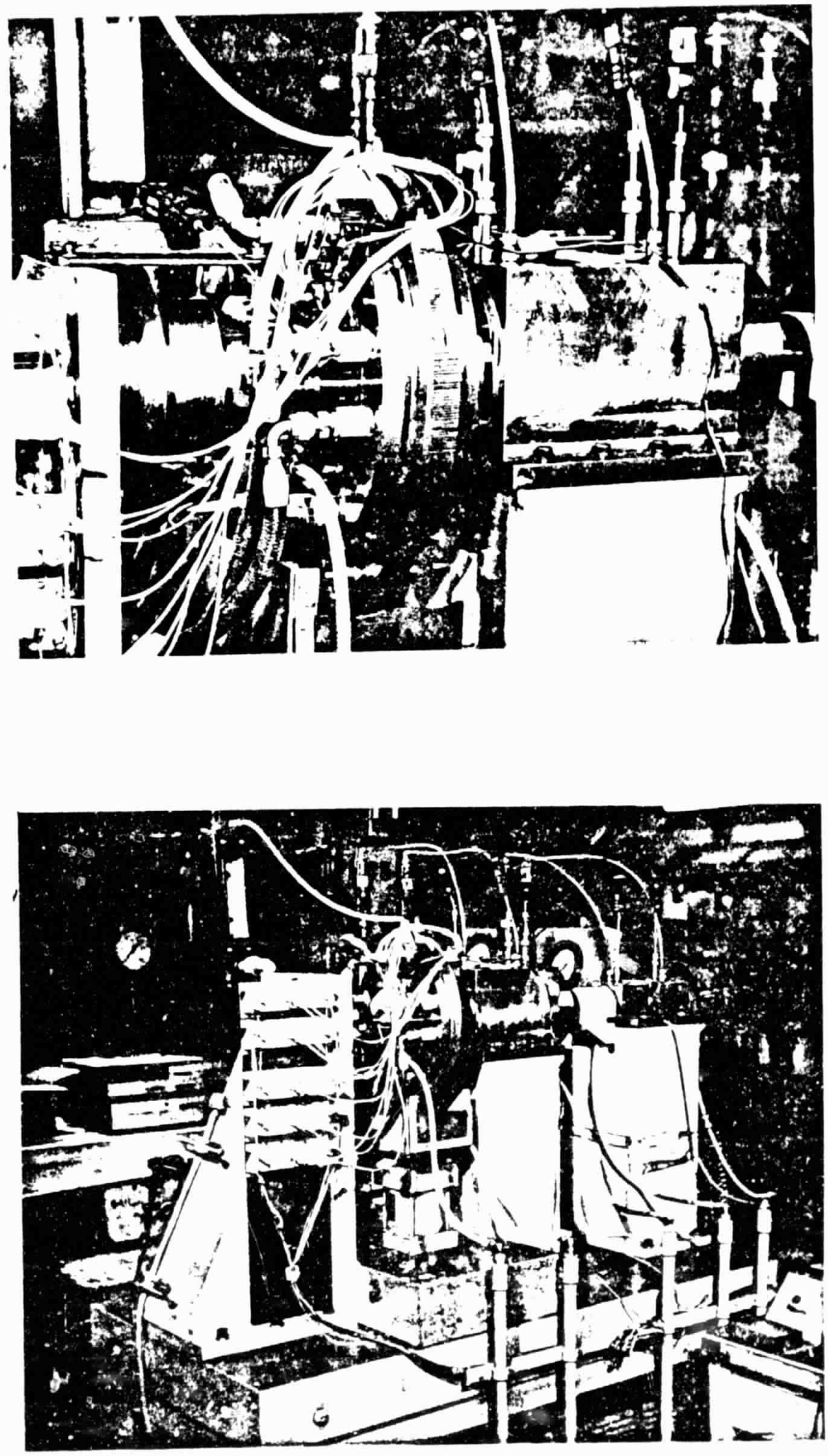

FIGURE 18: SPHERICAL ROLLER BEARING TEST RIG

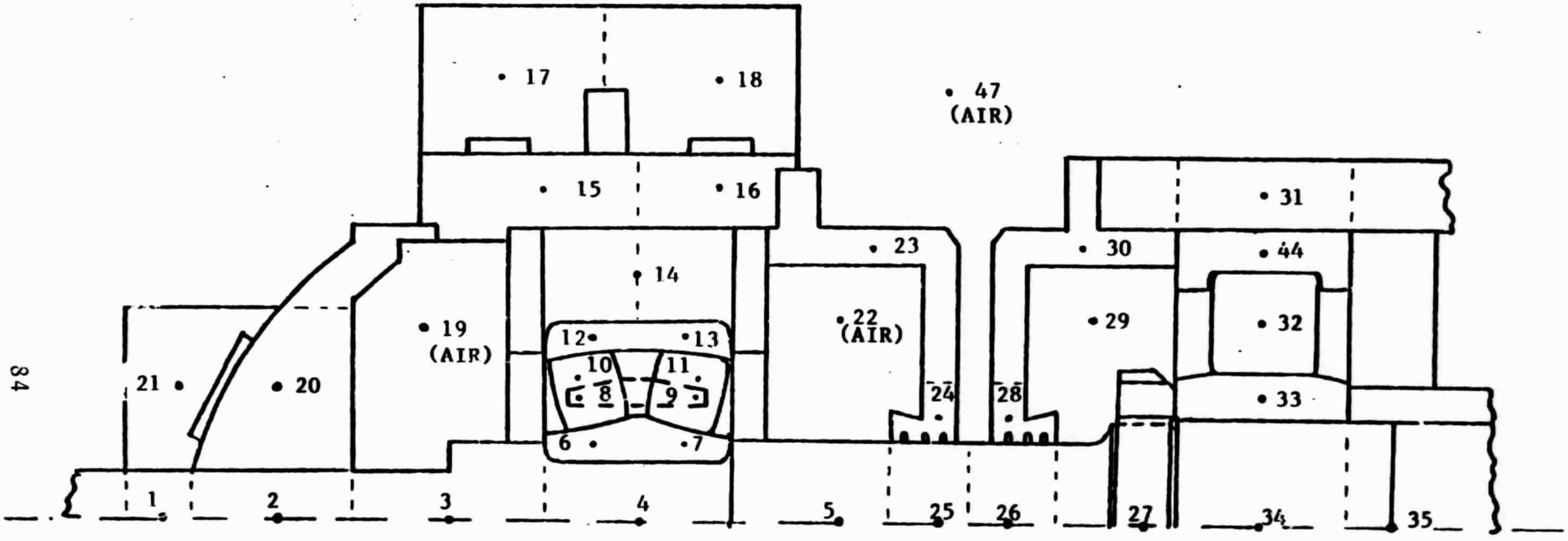

FIGURE 19 : SYSTEM MODEL USED IN EXAMPLE 1.
(METAL AND AIR NODES)

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FIGURE A2: USER SPECIFIED MATERIAL PROPERTIES CARD FORMAT (OPTION 2)

NOTES: Four cards required. All data items need not be specified. Those left blank will be set at the default values. Data items are specified in F10.0 format. Units are defined in Section 3.2.

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CARD 1

Columns 1–80

MODULUS OF ELASTICITY

SHAFT	OUTER RING	INNER RING	ROLLING ELEMENT	HOUSING

CARD 2

Columns 1–80

POISSON'S RATIO

SHAFT	OUTER RING	INNER RING	ROLLING ELEMENT	HOUSING

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C-2

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CARD 3

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

COEFFICIENT OF THERMAL EXPANSION				
SHAFT	OUTER RING	INNER RING	ROLLING ELEMENT	HOUSING

CARD 4

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

DENSITY				
SHAFT	OUTER RING	INNER RING	ROLLING ELEMENT	HOUSING

FIGURE A2 (continued): USER SPECIFIED MATERIAL PROPERTIES CARD FORMAT (OPTION 2)

FIG. A3: USER SPECIFIED SLICE WIDTH CARD FORMATS (OPTION 3)[1]

CARD 1

Columns 1–10	Columns 11–20	Columns 21–30	Columns 31–40	Columns 41–50	Columns 51–60	Columns 61–70	Columns 71–80
F10.0	F10.0						
WIDTH OF SLICE NUMBER 1	WIDTH OF SLICE NUMBER 2	ETC.					

SLICE WIDTH ACROSS SYMMETRIC HALF OF OUTER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED).

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CARD 2

Columns 1–10	Columns 11–20	Columns 21–30	Columns 31–40	Columns 41–50	Columns 51–60	Columns 61–70	Columns 71–80
F10.0	F10.0						
WIDTH OF SLICE NUMBER 1	WIDTH OF SLICE NUMBER 2	ETC.					

SLICE WIDTHS ACROSS SYMMETRIC HALF OF INNER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED).

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[1]User may input slice widths in inches (METRIC = .FALSE.) or millimeters (METRIC = .TRUE.)

FIG. A4: USER INPUT SYMMETRIC ROLLER GEOMETRY CARD FORMAT (OPTION 4)

CARD 1

1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
F10.0	F10.0						
SYMMETRIC ROLLER RADII AT SLICE ENDS ACROSS OUTER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED)							
RADIUS NO. 1	RADIUS NO. 2	RADIUS NO. 3	ETC.				

CARD 2

1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
F10.0	F10.0						
SYMMETRIC ROLLER RADII AT SLICE ENDS ACROSS INNER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED)							
RADIUS NO. 1	RADIUS NO. 2	RADIUS NO. 3	ETC.				

NOTES:

1. Input data sequence is shown in Figure 16.
2. User may input radii in inches (METRIC = .FALSE.) or millimeters (METRIC = .TRUE.).

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NOTES: 1. Input data sequence is shown in Figure 17.

2. User may input data in inches (METRIC = .FALSE.) or millimeters (METRIC = .TRUE.)

FIG. A5: USER SPECIFIED, COMPLETELY VARIABLE, ROLLER GEOMETRY CARD FORMATS (OPTION 5)

CARD 1

Columns 1–10	Columns 11–20	Columns 21–30	Columns 31–40	Columns 41–50	Columns 51–60	Columns 61–70	Columns 71–80
F10.0	F10.0						
SLICE WIDTHS ACROSS THE OUTER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED)							
WIDTH OF SLICE NUMBER 1	WIDTH OF SLICE NUMBER 2	ETC.					

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CARD 2

Columns 1–10	Columns 11–20	Columns 21–30	Columns 31–40	Columns 41–50	Columns 51–60	Columns 61–70	Columns 71–80
F10.0	F10.0						
ROLLER RADII AT SLICE ENDS ACROSS THE OUTER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED)							
RADII NUMBER 1	RADII NUMBER 2	ETC.					

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CARD 3

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

X COORDINATE
OF FIRST RADIUS
OUTER RING.

FIGURE A5 (CONTINUED): USER SPECIFIED, COMPLETELY VARIABLE, ROLLER GEOMETRY CARD FORMATS
(OPTION 5)

CARD 4

Columns 1–10	Columns 11–20	Columns 21–30	Columns 31–40	Columns 41–50	Columns 51–60	Columns 61–70	Columns 71–80
F10.0	F10.0						
SLICE WIDTHS ACROSS INNER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED)							
WIDTH OF SLICE NUMBER 1	WIDTH OF SLICE NUMBER 2	ETC.					

CARD 5

Columns 1–10	Columns 11–20	Columns 21–30	Columns 31–40	Columns 41–50	Columns 51–60	Columns 61–70	Columns 71–80
F10.0	F10.0						
ROLLER RADII AT SLICE ENDS ACROSS THE INNER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED)							
RADII NO. 1	RADII NO. 2	ETC.					

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FIG. A5 (CONTINUED) USER SPECIFIED, COMPLETELY VARIABLE, ROLLER GEOMETRY CARD FORMATS (OPTION 5)

CARD 6

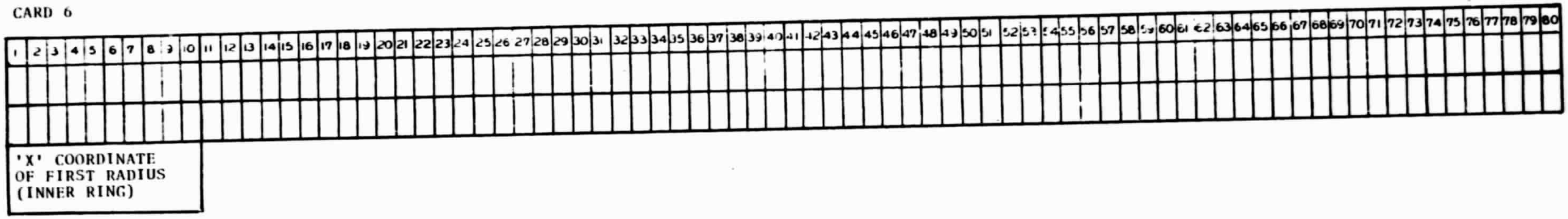

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FIGURE A5 (CONTINUED): USER SPECIFIED, COMPLETELY VARIABLE, ROLLER GEOMETRY CARD FORMATS (OPTION 5)

CARD 1 - TEMPERATURE CALCULATION CONTROL CARD

Field	M	N	TEMI	IPUNCH	IUB	IT1	EP1	IT2	EP2	START	STOP	STEP	TTIME	BTIME
Columns	1–5	6–10	11–15	16–20	21–25	26–30	31–35	36–40	41–50	51–55	56–60	61–65	66–70	71–80
Format (line 1)	I5	I5			I5 x	I5 x	F5.0 X	I5 x	F5.0 X	F5.0 X	F5.0 X	F5.0 X	I5.0 X	F5.0X
Format (line 2)			F5.0	I5 X										

GENERAL						STEADY STATE ONLY				TIME TRANSIENT ONLY					
HIGHEST NODE NUMBER	HIGHEST UNKNOWN NODE NUMBER. SAME AS NUMBER OF UNKNOWN NODES.	COMMON INITIAL TEMPERATURE (°C) SELECTED TEMPERATURES CAN BE GIVEN DIFFERENT INITIAL VALUES USING CARD 2.	PUNCH FLAG USUALLY ZERO. IF ≠ 0 FINAL TEMPERATURE WILL BE PUNCHED ACCORDING TO THE FORMAT OF CARD 2. THEN, THEY CAN BE READ IN AS INITIAL TEMPERATURES IN A LATER RUN.	OUTPUT FLAG, USUALLY ZERO, IF ≠ 0 BEARING OUTPUT AND A TEMPERATURE MAP WILL BE PRINTED EVERY TIME THE BEARING PROGRAM HAS BEEN CALLED.	MAXIMUM NO. OF CALLS OF THE BEARING PROGRAM.	ABSOLUTE ACCURACY OF TEMPERATURES (°C).	ITERATION LIMIT, USUALLY LEFT BLANK IF BLANK PRE-SET LIMIT IS USED	ACCURACY USUALLY LEFT BLANK.		STARTING TIME	STOPPING TIME	CALCULATION TIME STEP. IF LEFT BLANK, THE PROGRAM WILL CALCULATE A SUITABLE STEP.	TIME INTERVAL BETWEEN PRINTED TEMP. MAPS. THE INTERVAL WILL ALWAYS BE AT LEAST EQUAL TO THE CALC. TIME STEP.	TIME INTERVAL BETWEEN CALLS OF BEARING PROGRAM ALWAYS AT LEAST EQUAL TO THE CALC. TIME STEP.	
ITEM 1	ITEM 2	ITEM 3	ITEM 4	ITEM 5	ITEM 6	ITEM 7	ITEM 8	ITEM 9		ITEM 10	ITEM 11	ITEM 12	ITEM 13	ITEM 14	

FIGURE A6: INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION (OPTION 6)

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CARD 2 - NODE INITIAL TEMPERATURES (^{o}C)
USE AS MANY CARDS AS NEEDED FOLLOWED BY A BLANK CARD.

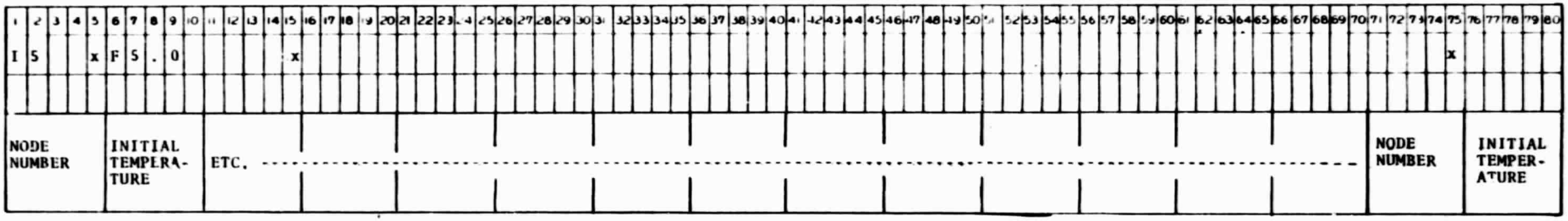

FIGURE A6 (CONTINUED): INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION (OPTION 6)

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CARD 3A - BEARING NODE NUMBERS, USE THIS CARD FOR ROW #1

Card columns	1–5	6–10	11–15	16–20	21–25	26–30	31–35	36–80
Field	OUTER RACE	INNER RACE	FLANGE	CAGE	INNER RING	ROLLERS	OUTER RING	(USE I5 FORMAT)
Mark in column	x (5)	x (10)	x (15)	x (20)	x (25)	x (30)	x (35)	

CARD 3B - BEARING NODE NUMBERS, USE FOR ROW #2

Card columns	1–5	6–10	11–15	16–20	21–25	26–30	31–35	36–80
Field	OUTER RACE	INNER RACE	FLANGE	CAGE	INNER RING	ROLLERS	OUTER RING	(USE I5 FORMAT)
Mark in column	x (5)	x (10)	x (15)	x (20)	x (25)	x (30)	x (35)	

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FIGURE A6 (CONTINUED): INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION (OPTION 6)

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CARD 3C - BEARING NODE NUMBERS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
				x					x					x																																																																	
BULK OIL					SHAFT					HOUSING					(USE I5 FORMAT)																																																																	

FIGURE A6 (CONTINUED): INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION (OPTION 6)

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CARD 4A - NODES WHERE BEARING HEAT IS GENERATED, USE THIS CARD FOR ROW #1

Columns 1–10	Columns 11–20	Columns 21–30	Columns 31–40	Columns 41–50	Columns 51–60	Columns 61–80
1 5 x 1 5 x	x x	x x	x x	x x	x x	
OUTER RACE	INNER RACE	DRAG	CAGE ROLLING ELEMENT	CAGE-LAND	FLANGE-ROLLING ELEMENT	
HALF THE HEAT IS GENERATED AT THIS NODE / HALF THE HEAT IS GENERATED AT THIS NODE THE ABOVE TWO NODE NUMBERS CAN BE THE SAME NUMBER.						

CARD 4B - NODES WHERE BEARING HEAT IS GENERATED, USE FOR ROW #2

Columns 1–10	Columns 11–20	Columns 21–30	Columns 31–40	Columns 41–50	Columns 51–60	Columns 61–80
x x	x x	x x	x x	x x	x x	
OUTER RACE	INNER RACE	DRAG	CAGE-ROLLING ELEMENT	CAGE-LAND	FLANGE-ROLLING ELEMENT	

USER NOTE: FOR A NON-FLANGED BEARING, FLANGE NODE CAN BE INPUT AS INNER RACE NODE.

FIGURE A6 (CONTINUED): INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION (OPTION 6)

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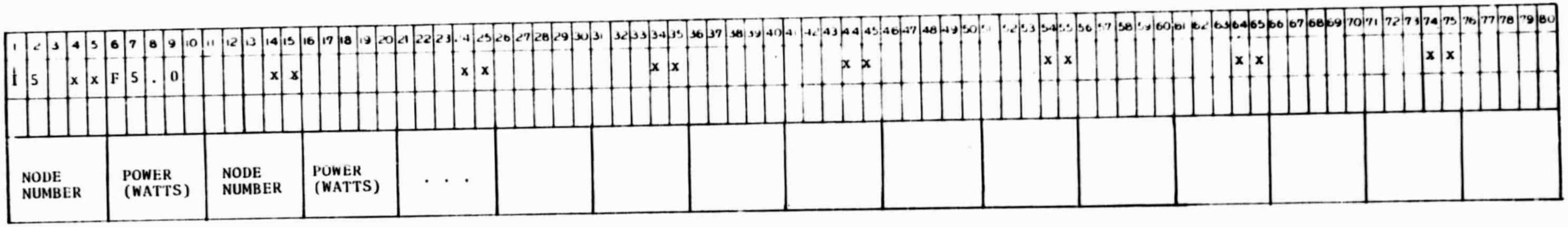
CARD 5 - NODES THAT GENERATE HEAT
USE AS MANY CARDS AS NEEDED, FOLLOWED BY A BLANK CARD



USER NOTES: 1) HEAT GENERATION RATE MUST BE CONSTANT

FIGURE A 6 (CONTINUED): INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION (OPTION 6)

CARD 6 - HEAT TRANSFER COEFFICIENTS
ONE OR TWO CARDS/COEFFICIENT, AS MANY AS NEEDED, FOLLOWED BY A BLANK CARD.

1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
I10 x	xF10.0						
INDEX FOR LATER IDENTIFICATION OF THE HEAT TR. COEFFICIENT. 1-10 $q = \lambda A/l\,\Delta t$ 11-20 $q = \alpha A \Delta t^a$ 21-30 $q = \alpha A \Delta t$ 31-40 $q = \epsilon k(Ti_i^4 - T_j^4)$ 41-50 FLUID FLOW	(CONDUCTIVITY) (FREE CONV. NO.) α (FORCED CONV. NO.) (EMISSIVITY, $0<\epsilon<1$) ϵ $\rho \cdot C_\rho \cdot V (w/^oC)$	a (If BLANK = 1.25) (ρ is DENSITY, KG/M^3, C_ρ SPECIFIC HEAT, $WSEC/KG^oC$, V VOLUME FLOW M^3/SEC.					

THE FORCED CONVECTION NO. α CAN BE CALCULATED BY THE PROGRAM FROM THE FORMULA: $\alpha = \lambda_{oil}/L$ Nu, WHERE: $Nu = K \cdot Re^A P_r^B$, $Re = (U L \rho)/\eta$, $P_r = \eta c_p/\lambda_{oil}$, η = constant, OR = f(TEMP.), η = DYNAMIC VISCOSITY, THEN THE FOLLOWING DATA MUST BE GIVEN AND A SECOND CARD MUST IMMEDIATELY FOLLOW, USE ONE OF THE 3 OPTIONS.

1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
21-30 (α=CONST.) 21-30 ($\alpha = c\eta^D, \eta=\eta(t)$) 21-30 ($\alpha=\alpha(\eta(t))$)	K C K	A D A	B BLANK B	L METER BLANK L METER	U(M/SEC) BLANK U	λ_{oil} BLANK λ_{oil}	(OPTION 1) (OPTION 2) (OPTION 3)

1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
DYNAMIC VISCOSITY (N/m^2S) BLANK BLANK	DENSITY (KG/M^3) BLANK DENSITY	SPECIFIC HEAT (WS/KG^oC) BLANK SPECIFIC HEAT	BLANK LOW TEMP. T_L (°C) T_L	BLANK DYNAMIC VISCOSITY AT T_L DYNAMIC VISCOSITY AT T_L	BLANK HIGH TEMP. T_H (°C) T_H	BLANK DYNAMIC VISC. AT T_H DYNAMIC VISC. AT T_H	(OPTION 1) (OPTION 2) (OPTION 3)

FIGURE A 6 (CONTINUED): INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION (OPTION 6)

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CARD 7 - HEAT FLOW PATHS; USE AS MANY CARDS AS NEEDED, FOLLOWED BY A BLANK CARD

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
								x	x				x	x				x	x																																																												

INDEX (INDAB = |INDEX|)	NODE i	NODE j				
$1 \le$ INDAB ≤ 10	NODE i	NODE j	L_1 mm	L_2 mm	L_3mm	CONDUCTION BETWEEN i AND j. AREA = $2\pi L_2 L_1$. IF INDEX < 0 AREA = L_1, L_2. DISTANCE $i-j = L_3$.
$11 \le$ INDAB ≤ 20	NODE i	NODE j	L_1	L_2	BLANK	NATURAL CONVECTION BETWEEN i AND j. AREA = $2\pi L_1 L_2$. IF INDEX 0 AREA = $L_1 L_2$.
$21 \le$ INDAB ≤ 30	NODE i	NODE j	L_1	L_2	BLANK	FORCED CONVECTION BETWEEN i AND j. AREA AS ABOVE. IF $\eta(t)$, t is tj.
$31 \le$ INDAB ≤ 40	NODE i	NODE j	L_1	L_2	(L_3)	RADIATION BETWEEN i AND j. AREA AS ABOVE, FOR DESCRIPTION OF L_3, SEE USER'S MANUAL.
$41 \le$ INDEX ≤ 50	NODE i	NODE j	INDEX OF FLUID FLOW NODE i to j, $41 \le$ INDEX ≤ 50	BLANK	BLANK	FLUID FLOW FROM NODE i TO NODE j. FIRST INDEX IS INDEX OF FLUID AT NODE i. SECOND INDEX REPRESENTS FLUID FLOW GOING FROM NODE i TO NODE j.
INDEX = 51	NODE i	NODE j	CONTACT FLAG 1, OUTER RACE ROW #1 2, OUTER RACE ROW #2 3, INNER RACE ROW #1 4, INNER RACE ROW #2 5, FLANGE ROW #1 6, FLANGE ROW #2	BLANK	BLANK	CONDUCTION THROUGH A BEARING

FIGURE A6 (CONTINUED): INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION (OPTION 6)

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CARD 8 - NODAL HEAT CAPACITIES (USE ONLY FOR TRANSIENT CALCULATIONS)

ONE CARD PER NODE

Columns 1–10	Columns 11–20	Columns 21–30	Columns 31–40	Columns 41–50	Columns 51–60	Columns 61–70	Columns 71–80
x x (columns 9, 10)							
Node Number If it is given without a sign, rotational symmetry is assumed and the volume is multiplied by 2Π. If it is negative the volume is not changed.	Volume at Node = L_1 L_2 L_3 L_1 mm	L_2 mm	L_3 mm	Density (KG/M^3)	Specific Heat WS/KG^oC		

FIGURE A 6 (CONTINUED): INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION (OPTION 6)

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APPENDIX B:

HEAT TRANSFER COMPUTATION NOTES

B.1 BASIC EQUATIONS*

B.1.1 Heat Conduction

The rate of heat flow $q_{ci,j}$(W) that is conducted from node i to node j may be expressed by,

$$q_{ci,j} = \frac{\lambda_{ij} A_{ij}}{L_{ij}} (t_i - t_j)$$

t_i and t_j are the temperatures at i and j, respectively, $A_{i,j}$ the area normal to the heat flow, (m^2) L_{ij} the distance (m) and λ_{ij} the thermal conductivity between i and j, (W/m°C).

Assuming that the structure between point i and j is composed of different materials, an equivalent heat conductivity may be calculated as follows:

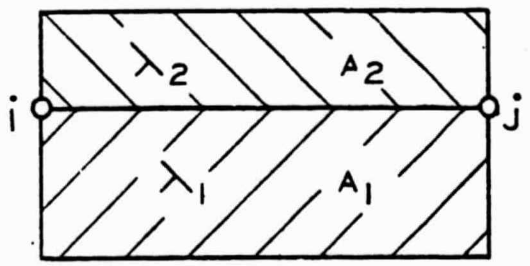

Fig. B-1

$$\lambda_{ij} = \frac{\lambda_1 A_1 + \lambda_2 A_2}{A_{ij}}$$

$$A_{ij} = A_1 + A_2$$

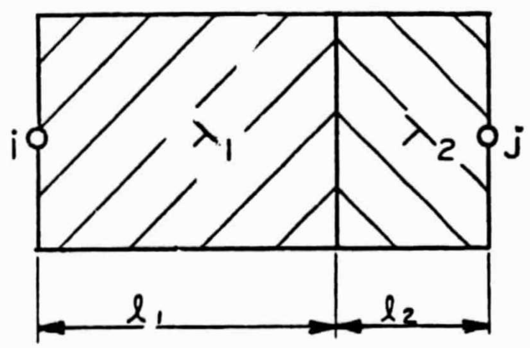

Fig. B-2

$$\lambda_{ij} = \frac{\ell_{ij}}{\ell_1/\lambda_1 + \ell_2/\lambda_2}$$

$$\ell_{ij} = \ell_1 + \ell_2$$

The calculation of the areas will be discussed in Section B.1.5.

---

*This Appendix is based on the material presented in Reference 5.

B.1.2 Convection

The rate of heat flow that is transferred between a solid structure and air by free convection may be expressed by

$$q_{vi,j} = \alpha_{i,j} \cdot A_{i,j} \cdot | t_i - t_j |^{1.25} \cdot \mathrm{SIGN}\ (t_i - t_j)$$

where

$$\mathrm{SIGN} = \begin{cases} 1, \text{ if } (t_i - t_j) \geq 0 \\ -1, \text{ if } (t_i - t_j) < 0 \end{cases}$$

in which

$$\alpha_{ij} = \begin{cases} 2.5 \cdot 10^{-2}\ \mathrm{W/m^2 - (degC)^{1.25}} \text{ for hot surfaces facing upward and cold surfaces facing downward} \\ 1.4 \cdot 10^{-2}\ \mathrm{W/m^2 - (degC)^{1.25}} \text{ for hot surfaces facing downward and cold surfaces facing upward} \\ 1.8 \cdot 10^{-2}\ \mathrm{W/m^2 - (degC)^{1.25}} \text{ for vertical surfaces} \end{cases}$$

For other special conditions, α_{ij} must be estimated by referring to heat transfer literature.

The rate of heat flow that is transferred between a solid structure and a fluid by forced convection may be expressed by

$$q_{ni,j} = \alpha_{i,j}\ A_{i,j}\ (t_i - t_j)$$

in which α_{ij} is the convective heat transfer coefficient.

Now, with $\alpha = \alpha_{ij}$, introduce the Nusselt number

$$N_u = \frac{\alpha L}{\lambda}$$

the Reynolds number

$$R_e = \frac{UL}{\nu}$$

and the Prandtl number

$$P_r = \frac{\rho \nu C_p}{\lambda}$$

where

L is a characteristic length which is equal to the diameter in the case of a cylindrical surface and is equal to the plate length in case of a flat surface (m).

U is a characteristic velocity which is equal to the difference between the fluid velocity at some distance from the surface and the surface velocity (m/sec).

λ is the fluid thermal conductivity (W/M°C)

ν is the fluid kinematic viscosity (M^2/sec)

ρ is the fluid density (kg/m^3)

C_p is the fluid specific heat (J/kg°C)

For given values of R_e and P_r the Nusselt number N_u and thus the heat transfer coefficient may be estimated from one of the following expressions:

Laminar flow along a flat plate: $R_e < 2300$

$$N_u = 0.323 \sqrt{R_e} \cdot \sqrt[3]{P_r}$$

Laminar flow of a liquid in a pipe:

$$N_u = 1.36 \sqrt[3]{R_e \cdot P_r(\frac{D}{L})}$$

where D is the pipe diameter and L the pipe length

Turbulent flow of a liquid in a pipe:

$$N_u = 0.027 \cdot R_e^{0.8} \cdot \sqrt[3]{P_r}$$

Gas flow inside and outside a tube:

$$N_u = 0.3 R_e^{0.57}$$

Liquid flow outside a tube:

$$N_u = 0.6 R_e^{0.5} \cdot P_r^{0.31}$$

Forced convection from the outer surface of a rotating shaft

$N_u = 0.11 \; [\; 0.5 \; R_e{}^2 \cdot P_r]^{0.35}$

where the Reynolds number R_e is developed by the shaft

$R_e = \frac{\omega\pi \; D^2}{\nu}$

in which ω is the angular velocity (rad/sec)

D is the shaft diameter (m)

The average coefficient of forced convection to the lubricating oil within a rolling contact bearing may be approximated by,

$$\alpha = 0.0986 \quad \{\frac{\omega}{\nu} \; [1 \pm \frac{D \cos \; (\beta)}{d_m}]\}^{\frac{1}{2}} \lambda (P_r)^{1/3}$$

using + for outer ring rotation

\- for inner ring rotation

in which ω is the bearing operating speed (rad/sec)

D is the diameter of the rolling elements (mm)

d_m is the bearing pitch diameter (mm)

β is the bearing contact angle; zero for cylindrical roller bearings (degrees)

B.1.3 <u>Fluid Flow</u>

The rate of heat flow that is transferred from fluid node i to fluid node j by fluid flow is

$$q_{fi,j} = \rho \dot{V}_{ij} \; C_p \; (t_i - t_j)$$

$\dot{V}_{ij}$ is the volume rate of flow from i to j. It must be observed that the continuity of mass requires the following equation to be satisfied

$$\Sigma \dot{V}_{ij} = 0$$

provided the fluid density is constant. The summation should be extended over all nodes i within the fluid which have heat exchange with node j by fluid flow.

B.1.4 Heat Radiation

The rate of heat flow that is radiated to node j from node i is expressed by

$$q_{Ri,j} = \delta_{i,j} \{(t_i + 273)^4 - (t_j + 273)^4\}$$

where

$$T_j = t_j + 273.16$$

$$T_i = t_i + 273.16$$

and the value of the coefficient $\delta_{i,j}$ depends on the geometry and the emissivity or the absorptivity of the bodies involved.

For radiation between large, parallel and adjacent surfaces of equal area, $A_{i,j}$ and emissivity, $\varepsilon_{i,j}$, $\delta_{i,j}$ is obtained from the equation

$$\delta_{i,j} = \varepsilon_{i,j} \, \sigma A_{i,j}$$

where σ, the Stefan-Boltzmann constant, is

$$\sigma = 5.76 \cdot 10^{-8} \text{ W/m}^2/(\text{degK})^4$$

For radiation between concentric spheres and coaxial cylinders of equal emissivity, $\varepsilon_{i,j}$, $\delta_{i,j}$ is given by the equation

$$\delta_{ij} = \frac{\varepsilon_{i,j} \, \sigma A_{i,j}}{1 + (1 - \varepsilon_{i,j}) \frac{A_{i,j}}{A^*_{i,j}}}$$

where σ is as above $A_{i,j}$ is the area of the enclosed body and $A^*_{i,j}$ is the area of the surrounding body, i.e., $A_{i,j} < A^*_{i,j}$.

Expressions for $\delta_{i,j}$ that are valid for more complicated geometries or for different emissivities may be found in the heat transfer literature.

B.1.5 Calculation of Areas

In the case of heat transfer in the axial direction $A_{i,j}$ is given by the equation (Fig. B-3)

$$A_{i,j} = 2\Pi r_m \cdot \Delta r$$

Referring to the temperature calculation input instructions, card 7, but recalling L must be input in mm not m.

$$L_1 = r_m = \frac{r_1 + r_2}{2}$$

$$L_2 = \Delta r = r_2 - r_1$$

In the case of heat transfer in the radial direction, $A_{i,j}$ is obtained from the expression

$$A_{i,j} = 2\Pi r_m \cdot H; \; L_1 = r_m; \; L_2 = H$$

and similarly for the radiation term above

$$A^*_{i,j} = 2\Pi r^*_m H$$

$$L_3 = r^*_m$$

$$L_2 = 2H$$

in which H is the length of the cylindrical surface; where heat is conducted between i and j, r_m is given by the same equation as above (Fig B-4 (a)); where heat is convected between i and j, r_m is the radius of the cylindrical surface (Fig. B-4(b)); where heat is radiated between i and j, r_m is the radius of the enclosed cylindrical surface and r_m* the radius of the surrounding cylindrical surface (Fig. B-4(c)).

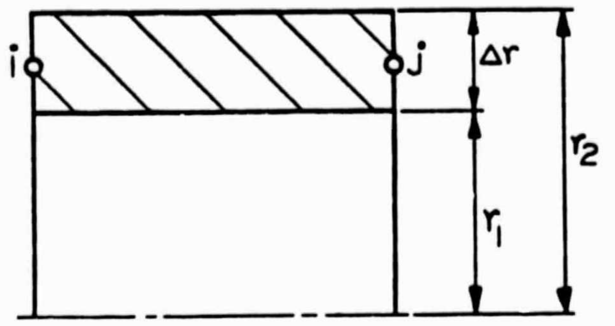

Fig. B-3

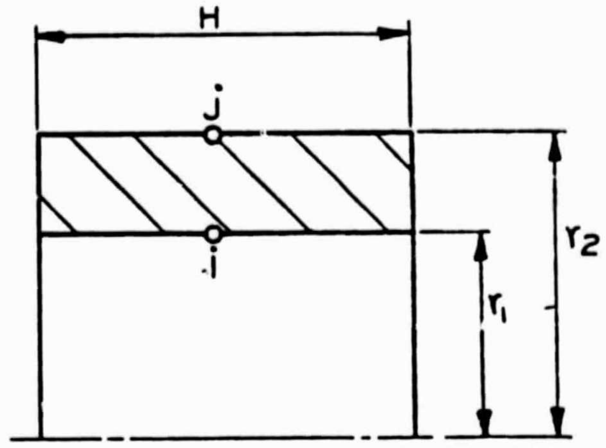

Fig. B-4(a)

B.2 TRANSIENT ANALYSIS

For the transient analysis all of the data pertaining to the node to node heat transfer coefficients must be provided by the input. Additionally, the volume and the specific heat at each node is required. For metal nodes this input is straightforward. To date, fluid nodal volume in a free space such as the bearing cavity, has not been correlated with lubricant flow rate or application method.

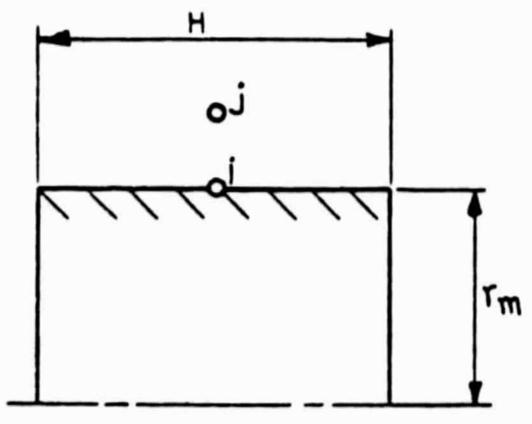

Fig. B -4(b)

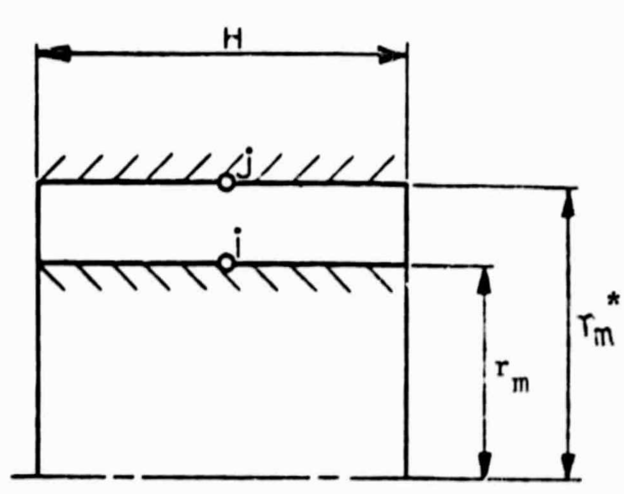

Fig. B -4(c)

APPENDIX C

SPHERBEAN OUTPUT, EXAMPLE PROBLEM 1

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**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

STEADY STATE TEMPERATURE CALCULATION. ITERATION LIMIT   5. ABSOLUTE ACCURACY  2.00 DEGREES

NODE POINTERS

        ROW #1
          O.RACE   I.RACE  FLANGE      CAGE      I.RING  ROLLERS  O.RING
            12        6       6           8        6        10       12

        ROW #2
          O.RACE   I.RACE  FLANGE      CAGE      I.RING  ROLLERS  O.RING
            13        7       7           9        7        11       13

          BULK OIL    SHAFT   HOUSING
             33         4        14

NODES WHERE BEARING HEAT IS GENERATED

        ROW #1
          OUTER RACE   INNER RACE    R.F.DRAG     CAGE-R.F.    CAGE-LAND   FLANGE-RE
          12     10      6     10    10     38     8     10    8     38     6     10

        ROW #2
          OUTER RACE   INNER RACE    R.F.DRAG     CAGE-R.F.    CAGE-LAND   FLANGE-RE
          13     11      7     11    11     38     9     11    9     38     7     11

CONSTANT GENERATED HEATS

        NODE  GEN. HEAT     NODE  GEN. HEAT     NODE  GEN. HEAT     NODE  GEN. HEAT     NODE  GEN. HEAT

          24      6.70        26      6.70        32     60.00        33     60.00        44     60.00
```

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PROGRAM OUTPUT, EXAMPLE 1: PAGE 1

**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

HEAT TRANSFER COEFFICIENTS

TYPE	INDEX	COEFFICIENTS	
CONDUCTION	1	53.6000	
CONDUCTION	2	59.8000	
FREE CONVECTION	11	5.00000	1.00000
FREE CONVECTION	12	10.0000	1.00000
FORCED CONVECTION	21	430.000	
FORCED CONVECTION	22	67.0000	
FORCED CONVECTION	23	177.000	
FORCED CONVECTION	24	98.4000	
FLUID FLOW	41	16.3000	
FLUID FLOW	42	37.5000	
FLUID FLOW	43	100.000	
FLUID FLOW	44	462.000	
FLUID FLOW	45	516.000	

PROGRAM OUTPUT, EXAMPLE 1: PAGE 2

**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

DESCRIPTION OF THE GEOMETRY AND INDICATION OF THE TYPES AND PATHS OF HEAT TRANSFER

ALL LENGTHS ARE IN MILLIMETERS, A NEGATIVE SIGN OF THE INDEX MEANS NO ROTATIONAL SYMMETRY

TYPE OF HEAT TR.	INDEX		NODE		NODE	1ST LENGTH	2ND LENGTH	3RD LENGTH
CONDUCTION	1	BETWEEN	1	AND	2	6.0000	10.0000	23.0000
CONDUCTION	1	BETWEEN	1	AND	21	20.0000	27.0000	30.0000
CONDUCTION	1	BETWEEN	2	AND	20	20.0000	30.0000	30.0000
CONDUCTION	2	BETWEEN	2	AND	3	15.0000	10.0000	32.0000
CONDUCTION	1	BETWEEN	20	AND	15	60.0000	15.0000	75.0000
CONDUCTION	1	BETWEEN	15	AND	16	80.0000	25.0000	35.0000
CONDUCTION	1	BETWEEN	15	AND	14	65.0000	22.0000	22.0000
CONDUCTION	1	BETWEEN	17	AND	18	110.0000	40.0000	35.0000
CONDUCTION	1	BETWEEN	14	AND	15	65.0000	20.0000	22.0000
CONDUCTION	1	BETWEEN	14	AND	12	45.0000	12.0000	15.0000
CONDUCTION	1	BETWEEN	14	AND	13	45.0000	12.0000	15.0000
CONDUCTION	1	BETWEEN	12	AND	13	42.0000	7.0000	17.0000
CONDUCTION	1	BETWEEN	5	AND	7	23.0000	7.0000	15.0000
CONDUCTION	1	BETWEEN	6	AND	4	20.0000	17.0000	23.0000
CONDUCTION	1	BETWEEN	7	AND	4	20.0000	17.0000	23.0000
CONDUCTION	1	BETWEEN	4	AND	5	12.0000	18.0000	34.0000
CONDUCTION	1	BETWEEN	26	AND	25	12.0000	24.0000	15.0000
CONDUCTION	1	BETWEEN	26	AND	27	12.0000	24.0000	15.0000
CONDUCTION	1	BETWEEN	5	AND	25	12.0000	24.0000	15.0000
CONDUCTION	1	BETWEEN	27	AND	34	14.0000	27.0000	23.0000
CONDUCTION	1	BETWEEN	34	AND	35	14.0000	29.0000	22.0000
CONDUCTION	1	BETWEEN	16	AND	23	65.0000	15.0000	30.0000
CONDUCTION	1	BETWEEN	23	AND	24	42.0000	6.0000	32.0000
CONDUCTION	1	BETWEEN	24	AND	25	20.0000	10.0000	30.0000
CONDUCTION	1	BETWEEN	28	AND	26	20.0000	10.0000	30.0000

PROGRAM OUTPUT, EXAMPLE 1: PAGE 3

**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

DESCRIPTION OF THE GEOMETRY AND INDICATION OF THE TYPES AND PATHS OF HEAT TRANSFER

ALL LENGTHS ARE IN MILLIMETERS. A NEGATIVE SIGN OF THE INDEX MEANS NO ROTATIONAL SYMMETRY

TYPE OF HEAT TR.	INDEX		NODE		NODE	1ST LENGTH	2ND LENGTH	3RD LENGTH
CONDUCTION	1	BETWEEN	28	AND	30	42.0000	6.0000	32.0000
CONDUCTION	1	BETWEEN	30	AND	31	65.0000	28.0000	30.0000
CONDUCTION	1	BETWEEN	30	AND	44	60.0000	9.0000	25.0000
CONDUCTION	1	BETWEEN	31	AND	44	65.0000	33.0000	15.0000
CONDUCTION	1	BETWEEN	33	AND	34	30.0000	33.0000	34.0000
CONDUCTION	1	BETWEEN	15	AND	17	20.0000	90.0000	30.0000
CONDUCTION	1	BETWEEN	16	AND	18	20.0000	90.0000	30.0000
FREE CONVECTION	11	BETWEEN	21	AND	47	55.0000	50.0000	
FREE CONVECTION	11	BETWEEN	15	AND	47	80.0000	20.0000	
FREE CONVECTION	11	BETWEEN	16	AND	47	80.0000	20.0000	
FREE CONVECTION	11	BETWEEN	17	AND	47	100.0000	93.4000	
FREE CONVECTION	11	BETWEEN	18	AND	47	100.0000	93.4000	
FREE CONVECTION	11	BETWEEN	23	AND	47	50.0000	62.0000	
FREE CONVECTION	11	BETWEEN	30	AND	47	50.0000	50.0000	
FREE CONVECTION	11	BETWEEN	31	AND	47	80.0000	45.0000	
FREE CONVECTION	12	BETWEEN	20	AND	19	40.0000	45.0000	
FREE CONVECTION	12	BETWEEN	15	AND	19	20.0000	60.0000	
FREE CONVECTION	12	BETWEEN	14	AND	19	20.0000	52.0000	
FORCED CONVECTION	22	BETWEEN	3	AND	19	30.0000	15.0000	
FREE CONVECTION	12	BETWEEN	14	AND	22	50.0000	18.0000	
FREE CONVECTION	12	BETWEEN	23	AND	22	40.0000	67.0000	
FREE CONVECTION	12	BETWEEN	30	AND	29	40.0000	67.0000	
FORCED CONVECTION	21	BETWEEN	44	AND	36	31.0000	55.0000	
FORCED CONVECTION	21	BETWEEN	33	AND	36	31.0000	38.0000	
FORCED CONVECTION	21	BETWEEN	32	AND	36	50.0000	52.0000	

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PROGRAM OUTPUT, EXAMPLE 1: PAGE 4

**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

DESCRIPTION OF THE GEOMETRY AND INDICATION OF THE TYPES AND PATHS OF HEAT TRANSFER

ALL LENGTHS ARE IN MILLIMETERS, A NEGATIVE SIGN OF THE INDEX MEANS NO ROTATIONAL SYMMETRY

TYPE OF HEAT TR.	INDEX		NODE		NODE	1ST LENGTH	2ND LENGTH	3RD LENGTH
FORCED CONVECTION	21	BETWEEN	6	AND	38	27.0000	17.0000	
FORCED CONVECTION	21	BETWEEN	7	AND	38	27.0000	17.0000	
FORCED CONVECTION	21	BETWEEN	12	AND	38	40.0000	17.0000	
FORCED CONVECTION	21	BETWEEN	13	AND	38	40.0000	17.0000	
FORCED CONVECTION	21	BETWEEN	10	AND	38	50.0000	25.2000	
FORCED CONVECTION	21	BETWEEN	11	AND	38	50.0000	25.2000	
FORCED CONVECTION	21	BETWEEN	9	AND	38	20.0000	34.0000	
FORCED CONVECTION	21	BETWEEN	8	AND	38	20.0000	34.0000	
FORCED CONVECTION	22	BETWEEN	5	AND	22	20.0000	25.0000	
FORCED CONVECTION	22	BETWEEN	27	AND	29	40.0000	15.0000	
FORCED CONVECTION	23	BETWEEN	17	AND	40	100.0000	37.0000	
FORCED CONVECTION	23	BETWEEN	18	AND	40	100.0000	37.0000	
FORCED CONVECTION	23	BETWEEN	15	AND	40	80.0000	37.0000	
FORCED CONVECTION	23	BETWEEN	16	AND	40	80.0000	37.0000	
FORCED CONVECTION	24	BETWEEN	20	AND	42	50.0000	33.0000	
FORCED CONVECTION	24	BETWEEN	21	AND	42	50.0000	33.0000	
FLUID FLOW	45	FROM	49	TO	45	(INDEX 41)		
FLUID FLOW	41	FROM	45	TO	38	(INDEX 41)		
FLUID FLOW	41	FROM	38	TO	39	(INDEX 41)		
FLUID FLOW	41	FROM	39	TO	49	(INDEX 41)		
FLUID FLOW	45	FROM	47	TO	50	(INDEX 42)		
FLUID FLOW	42	FROM	50	TO	36	(INDEX 42)		
FLUID FLOW	42	FROM	36	TO	37	(INDEX 42)		
FLUID FLOW	42	FROM	37	TO	49	(INDEX 42)		
FLUID FLOW	45	FROM	49	TO	45	(INDEX 43)		

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PROGRAM OUTPUT, EXAMPLE 1: PAGE 5

**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

DESCRIPTION OF THE GEOMETRY AND INDICATION OF THE TYPES AND PATHS OF HEAT TRANSFER

ALL LENGTHS ARE IN MILLIMETERS. A NEGATIVE SIGN OF THE INDEX MEANS NO ROTATIONAL SYMMETRY

TYPE OF HEAT TR.	INDEX		NODE		NODE	1ST LENGTH	2ND LENGTH	3RD LENGTH
FLUID FLOW	43	FROM	46	TO	42	(INDEX 43)		
FLUID FLOW	43	FROM	42	TO	43	(INDEX 43)		
FLUID FLOW	43	FROM	43	TO	49	(INDEX 43)		
FLUID FLOW	45	FROM	49	TO	48	(INDEX 44)		
FLUID FLOW	44	FROM	48	TO	40	(INDEX 44)		
FLUID FLOW	44	FROM	40	TO	41	(INDEX 44)		
FLUID FLOW	44	FROM	41	TO	43	(INDEX 44)		
BEARING CONDUCTION	51	BETWEEN	12	AND	10	1.0000		
BEARING CONDUCTION	51	BETWEEN	13	AND	11	2.0000		
BEARING CONDUCTION	51	BETWEEN	6	AND	10	3.0000		
BEARING CONDUCTION	51	BETWEEN	7	AND	11	4.0000		

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PROGRAM OUTPUT, EXAMPLE 1: PAGE 6

**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

T E M P E R A T U R E   M A P

TEMPERATURES ARE IN DEGREES CELSIUS. THE FIRST 44 TEMPERATURES ARE CALCULATED, THE OTHERS ARE KNOWN

STEADY STATE TEMPERATURE CALCULATION, INITIAL TEMPERATURES

CALCULATED TEMPERATURES

NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE
1	93.000	2	93.000	3	93.000	4	93.000	5	93.000
6	93.000	7	93.000	8	93.000	9	93.000	10	93.000
11	93.000	12	93.000	13	93.000	14	93.000	15	93.000
16	93.000	17	93.000	18	93.000	19	93.000	20	93.000
21	93.000	22	93.000	23	93.000	24	93.000	25	93.000
26	93.000	27	93.000	28	93.000	29	93.000	30	93.000
31	93.000	32	93.000	33	93.000	34	93.000	35	93.000
36	93.000	37	93.000	38	93.000	39	93.000	40	93.000
41	93.000	42	93.000	43	93.000	44	93.000		

KNOWN BOUNDARY TEMPERATURES

NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE
45	93.000	46	100.000	47	26.700	48	102.000	49	138.000
50	93.300								

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PROGRAM OUTPUT, EXAMPLE 1: PAGE 7

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**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

SPHERBEAN PROGRAM OPTIONS IN EFFECT :

     MOUNTED BEARING ANALYSIS
     THERMAL CALCULATIONS PERFORMED
     OUTER RING TREATED AS A FLEXURALLY RIGID ELASTIC SOLID
     ROLLERS ARE SYMMETRIC ABOUT THE Y-AXIS
     ALL SLICE WIDTHS ARE EQUAL

SOLUTION CONTROL PARAMETERS :

     PROGRAM EXECUTED AT LEVEL 2 WITH A TOLERANCE OF.10000E-01
     A MAXIMUM OF    20 ITERATIONS WERE USED IN THE SOLUTION LOOP
     EPICYCLIC SPEED MULTIPLIERS :
          ROTATIONAL - .10000E 01
          ORBITAL    - .10000E 01
```

ROLLER DATA AND GEOMETRY :

NUMBER OF ROLLERS PER ROW	NUMBER OF ROWS	ROLLER MAX DIAMETER (IN)	EFFECTIVE LENGTH OUTER RING (IN)	EFFECTIVE LENGTH INNER RING (IN)	ROLLER FLAT LENGTH (IN)	ROLLER CROWN RADIUS (IN)	ROLLER END SPHERE RADIUS (IN)
12	2	0.51220	0.46850	0.46850	0.0	1.57386	5.55120

ROLLER FLANGE END PLAY (IN)	AZIMUTHAL LOCATION OF FIRST ROLLER (RAD) ROW 1	ROW 2	X-COORDINATE OF ROLLER END SPHERE RADIUS ORIGIN (IN) ROW 1	ROW 2
0.00250	0.0	0.0	5.26400	5.26400

```
ROLLER PROFILE :
        SPHERICAL CROWN WITH Y-SYMMETRY
 NUMBER OF ROLLER SLICES FOR ROLLER SYMMETRIC HALF - 10
```

RING DATA AND GEOMETRY :

GROOVE RADIUS OUTER RING (IN)	GROOVE RADIUS INNER RING	DIAMETRAL CLEARANCE (IN)	CONTACT ANGLE (RAD)	FLANGE ANGLE (DEG)	INNER RING ROTATIONAL SPEED (RPM)
1.58976	1.63233	0.00200	0.24725	11.64	3000.0

PROGRAM OUTPUT, EXAMPLE 1: PAGE 8

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**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

CAGE DATA AND GEOMETRY :

TOTAL NUMBER OF CAGE GUIDE RAILS - 0
CAGE TYPE FLAG. 0 - ROLLER RIDING CAGE

RAIL LAND DIAMETER (IN)	SINGLE RAIL WIDTH (IN)	RAIL LAND DIAMETRAL CLEARANCE (IN)	POCKET RADIAL CLEARANCE (IN)	POCKET AXIAL CLEARANCE (IN)	WEB THICKNESS (IN)
0.0	0.0	0.0	0.01020	0.00000	0.13700

MATERIAL PROPERTIES :

	OUTER RING	INNER RING	ROLLING ELMT.	SHAFT	HOUSING
ELASTIC MODULUS (PSI)	29599872.0	29599872.0	29599872.0	29599872.0	29599872.0
POISSON'S RATIO	0.30	0.30	0.30	0.30	0.30
THERMAL EXP. COEFF. (1/F)	.0000067440	.0000067440	.0000067440	.0000067440	.0000067440
DENSITY (LB/IN3)	0.2800	0.2800	0.2800	0.2800	0.2800

LUBE SPECIFICATION AND PROPERTIES :

MCODE = 4 MIL-L-23699

N A S A LUBE FRICTION COEFF.	N A S A FILM THICKNESS COEFF.	REPLENISHMENT LAYER THICKNESS OUTER RING (IN)	INNER RING (IN)	FLANGE (IN)	FRACTION OF LUBE IN BEARING CAVITY	SLIDE/ROLL RATIO FRICTION LIMIT
0.070	18.20	0.27E-04	0.15E-04	0.50E-05	0.02	0.0050

PROGRAM OUTPUT, EXAMPLE 1: PAGE 9

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**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

SURFACE FINISH AND FATIGUE LIFE DATA :

        RMS SURFACE ROUGHNESS (IN)

 OUTER RING      INNER RING      ROLLER

0.64000E-05     0.63000E-05     0.53000E-05


APPLIED LOADS  (LBS) :

AXIAL LOAD   RADIAL LOAD(Y)   RADIAL LOAD(Z)

    0.0          3000.0            0.0
```

PROGRAM OUTPUT, EXAMPLE 1: PAGE 10

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**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****


   L-10 FATIGUE LIVES (HRS)

   OUTER RING
        ROW 1              0.116E 05
        ROW 2              0.116E 05
   INNER RING
        ROW 1              0.345E 03
        ROW 2              0.345E 03
   SINGLE ROW BEARING
              ROW 1        0.339E 03
              ROW 2        0.339E 03
   BEARING FATIGUE LIFE    0.183E 03

                                                                      USER INPUT LIFE MULTIPLIERS
   LUBE LIFE REDUCTION FACTORS, DUE TO H/SIGMA
                                                              O.R.           I.R.
                           O.R.            I.R.               1.000          1.000
        ROW 1              0.210           0.210
        ROW 2              0.210           0.210


   FILM THICKNESS TO SURFACE ROUGHNESS RATIO (H/SIGMA)
   FOR HEAVIEST LOADED ROLLING ELEMENT

                           O.R.            I.R.
        ROW 1              0.265           0.160
        ROW 2              0.265           0.160
```

PROGRAM OUTPUT, EXAMPLE 1: PAGE 11

**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

LUBRICANT DATA :

LUBE TYPE - MIL-L-23699

ROW#1	TEMP. (DEG F)	DENS (GM/ 3 /CM)	VISCOSITY (CSTK)	VISCOSITY (CPOIS)	PRESS. VIS. COEF. (1/PSI)
O.R.	225.5	0.887E 00	0.436E 01	0.387E 01	0.833E-04
I.R.	230.8	0.883E 00	0.414E 01	0.366E 01	0.821E-04
BULK	203.9	0.899E 00	0.515E 01	0.463E 01	0.872E-04

ROW#2	TEMP. (DEG F)	DENS (GM/ 3 /CM)	VISCOSITY (CSTK)	VISCOSITY (CPOIS)	PRESS. VIS. COEF. (1/PSI)
O.R.	225.5	0.887E 00	0.436E 01	0.387E 01	0.833E-04
I.R.	230.8	0.883E 00	0.414E 01	0.366E 01	0.821E-04
BULK	203.9	0.899E 00	0.515E 01	0.463E 01	0.872E-04

PROGRAM OUTPUT, EXAMPLE 1: PAGE 12

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**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

ROLLER RACEWAY CONTACT LOADS F (LBS) AND MOMENTS M (IN-LB) AT THE OUTER RING :

ROLLER	F-X	F-Y	F-Z	M-X	M-Y	M-Z
ROW#1						
1	0.153	-753.509	-15.299	-3.741	-2.570	0.206
2	0.153	-457.342	-4.676	-1.123	-1.247	0.207
3	0.156	-6.371	-0.029	0.005	0.0	0.206
4	0.0	-1.411	-0.008	0.001	0.0	-0.054
5	0.0	-1.411	-0.008	0.001	0.0	-0.054
6	0.0	-1.411	-0.008	0.001	0.0	-0.054
7	0.0	-1.411	-0.008	0.001	0.0	-0.054
8	0.0	-1.411	-0.008	0.001	0.0	-0.054
9	0.0	-1.411	-0.008	0.001	0.0	-0.054
10	0.0	-1.411	-0.008	0.001	0.0	-0.054
11	0.156	-6.371	-0.029	0.005	0.0	0.205
12	0.158	-457.342	-4.676	-1.123	-1.247	0.207
ROW#2						
1	0.153	-753.509	15.299	3.741	2.570	0.206
2	0.153	-457.342	4.676	1.123	1.247	0.207
3	0.156	-6.371	0.029	-0.005	0.0	0.206
4	0.0	-1.411	0.008	-0.001	0.0	-0.054
5	0.0	-1.411	0.008	-0.001	0.0	-0.054
6	0.0	-1.411	0.008	-0.001	0.0	-0.054
7	0.0	-1.411	0.008	-0.001	0.0	-0.054
8	0.0	-1.411	0.008	-0.001	0.0	-0.054
9	0.0	-1.411	0.009	-0.001	0.0	-0.054
10	0.0	-1.411	0.008	-0.001	0.0	-0.054
11	0.156	-6.371	0.029	-0.005	0.0	0.206
12	0.158	-457.342	4.676	1.123	1.247	0.207

PROGRAM OUTPUT, EXAMPLE 1: PAGE 13

**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

ROLLER RACEWAY CONTACT LOADS F (LBS) AND MOMENTS M (IN-LB) AT THE INNER RING :

ROLLER	F-X	F-Y	F-Z	M-X	M-Y	M-Z
ROW#1						
1	0.133	752.034	13.841	-5.038	1.837	-0.260
2	1.336	455.354	14.089	-3.583	0.888	0.031
3	0.139	4.374	0.005	0.002	0.0	-0.261
4	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0
11	0.130	4.374	0.005	0.002	0.0	-0.261
12	-0.340	455.911	14.089	-3.583	0.888	-0.553
ROW#2						
1	0.133	752.034	-13.841	5.038	-1.837	-0.260
2	1.336	455.354	-14.089	3.583	-0.888	0.031
3	0.139	4.374	-0.005	-0.002	0.0	-0.261
4	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0
11	0.138	4.374	-0.005	-0.002	0.0	-0.261
12	-0.346	455.911	-14.089	3.583	-0.888	-0.553

PROGRAM OUTPUT, EXAMPLE 1: PAGE 14

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**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

INNER RING APPLIED FORCES AND MOMENTS (LBS, IN-LB, IN) :

AXIAL LOAD= 0.0

RADIAL LOAD (Y)= 0.300000E 04 RADIAL MISALIGNMENT (Y) = 0.0
RADIAL LOAD (Z)= 0.0 RADIAL MISALIGNMENT (Z) = 0.0

INNER RING REACTIVE FORCES AND MOMENTS

	X	Y	Z
LOAD	0.85270-13	-0.29990 04	-0.47980 02
MOMENT	-0.10220 03	-0.46630-14	-0.88820-14

OTHER CALCULATED OUTPUT :

PITCH DIAMETER (IN)	OSCULATION OUTER RING	OSCULATION INNER RING
2.565	0.9900	0.9300

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PROGRAM OUTPUT, EXAMPLE 1: PAGE 15

**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

ROLLER NON-CONTACT FORCES,MOMENTS :

ROLLER	CENTRIFUGAL FORCE (LBS) X	Y	Z	GYRO-MOMENTS (IN-LB)
ROW#1				
1	-0.352	1.40	0.0	0.538E-01
2	-0.352	1.40	0.0	0.538E-01
3	-0.359	1.43	0.0	0.550E-01
4	-0.356	1.41	0.0	0.544E-01
5	-0.356	1.41	0.0	0.544E-01
6	-0.356	1.41	0.0	0.544E-01
7	-0.356	1.41	0.0	0.544E-01
8	-0.356	1.41	0.0	0.544E-01
9	-0.356	1.41	0.0	0.544E-01
10	-0.356	1.41	0.0	0.544E-01
11	-0.359	1.43	0.0	0.550E-01
12	-0.352	1.40	0.0	0.538E-01
ROW#2				
1	-0.352	1.40	0.0	0.538E-01
2	-0.352	1.40	0.0	0.538E-01
3	-0.359	1.43	0.0	0.550E-01
4	-0.356	1.41	0.0	0.544E-01
5	-0.356	1.41	0.0	0.544E-01
6	-0.356	1.41	0.0	0.544E-01
7	-0.356	1.41	0.0	0.544E-01
8	-0.356	1.41	0.0	0.544E-01
9	-0.356	1.41	0.0	0.544E-01
10	-0.356	1.41	0.0	0.544E-01
11	-0.359	1.43	0.0	0.550E-01
12	-0.352	1.40	0.0	0.538E-01

PROGRAM OUTPUT, EXAMPLE 1: PAGE 16

```
**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

  HEAT GENERATION RATES (WATTS)                                  PERCENT OF TOTAL HEAT GENERATED

 ROW#1

  SUM OF ROLLING ELT/O.R. CONTACT                 44.2            19.3
  SUM OF ROLLING ELT/I.R. CONTACT                 36.6            16.0
  SUM OF ROLLING ELT/DRAG                          1.3             0.6
  SUM OF ROLLING ELT/CAGE POCKET                  32.2            14.1
  SUM OF ROLLING ELT/CAGE LAND                     0.0             0.0

 ROW#2

  SUM OF ROLLING ELT/O.R. CONTACT                 44.2            19.3
  SUM OF ROLLING ELT/I.R. CONTACT                 36.6            16.0
  SUM OF ROLLING ELT/DRAG                          1.3             0.6
  SUM OF ROLLING ELT/CAGE POCKET                  32.2            14.1
  SUM OF ROLLING ELT/CAGE LAND                     0.0             0.0
  ---------------------------------------------------            -----
  TOTAL HEAT GENERATION                          228.6           100.0


                                                          ROW #1                       ROW #2
                                   (  OUTER RACEWAY   25.7 (    11.4 WATTS )      25.7 (    11.4 WATTS )
 PERCENT OF TOTAL HEAT GENERATED   (
 AT ALL ROLLER/RACEWAY CONTACTS    (
 BY ROLLING (HD) FRICTION          (  INNER RACEWAY   13.5 (     4.9WATTS )       13.5 (     4.9WATTS )


  BEARING CONDUCTANCE (WATTS/DEG C)

 ROW#1
  OUTER RING      INNER RING

     10.3            5.7
 ROW#2
  OUTER RING      INNER RING

     10.3            5.7
```

PROGRAM OUTPUT, EXAMPLE 1: PAGE 17

**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

RACEWAY CONTACT DATA :

ROLLER	HERTZ CONTACT STRESS (PSI) OUTER RING	INNER RING	FILM THICKNESS (IN) OUTER RING	INNER RING	EHD FRICTION COEFF. OUTER RING	INNER RING
ROW#1						
1	0.1324E 06	0.2953E 06	0.2307E-05	0.1321E-05	0.434E-01	0.428E-01
2	0.1489E 06	0.2481E 06	0.2458E-05	0.1612E-05	0.305E-01	0.408E-01
3	0.3378E 05	0.5154E 05	0.3041E-05	0.2397E-05	0.463E-02	0.111E-02
4	0.2260E 05	0.0	0.3201E-05	0.0	0.581E-02	0.0
5	0.2260E 05	0.0	0.3201E-05	0.0	0.581E-02	0.0
6	0.2260E 05	0.0	0.3201E-05	0.0	0.581E-02	0.0
7	0.2260E 05	0.0	0.3201E-05	0.0	0.581E-02	0.0
8	0.2260E 05	0.0	0.3201E-05	0.0	0.581E-02	0.0
9	0.2260E 05	0.0	0.3201E-05	0.0	0.581E-02	0.0
10	0.2260E 05	0.0	0.3201E-05	0.0	0.581E-02	0.0
11	0.3378E 05	0.5154E 05	0.3041E-05	0.2397E-05	0.463E-02	0.111E-02
12	0.1489E 06	0.2481E 06	0.2458E-05	0.1612E-05	0.305E-01	0.408E-01
ROW#2						
1	0.1324E 06	0.2953E 06	0.2307E-05	0.1321E-05	0.434E-01	0.428E-01
2	0.1489E 06	0.2481E 06	0.2458E-05	0.1612E-05	0.305E-01	0.408E-01
3	0.3378E 05	0.5154E 05	0.3041E-05	0.2397E-05	0.463E-02	0.111E-02
4	0.2260E 05	0.0	0.3201E-05	0.0	0.581E-02	0.0
5	0.2260E 05	0.0	0.3201E-05	0.0	0.581E-02	0.0
6	0.2260E 05	0.0	0.3201E-05	0.0	0.581E-02	0.0
7	0.2260E 05	0.0	0.3201E-05	0.0	0.581E-02	0.0
8	0.2260E 05	0.0	0.3201E-05	0.0	0.581E-02	0.0
9	0.2260E 05	0.0	0.3201E-05	0.0	0.581E-02	0.0
10	0.2260E 05	0.0	0.3201E-05	0.0	0.581E-02	0.0
11	0.3378E 05	0.5154E 05	0.3041E-05	0.2397E-05	0.463E-02	0.111E-02
12	0.1489E 06	0.2481E 06	0.2458E-05	0.1612E-05	0.305E-01	0.408E-01

PROGRAM OUTPUT, EXAMPLE 1: PAGE 18

S T A R V A T I O N   D A T A

ROLLER	STARVATION COEFFICIENT Outer	STARVATION COEFFICIENT Inner	MENISCUS DISTANCE (IN) Outer	MENISCUS DISTANCE (IN) Inner
ROW				
1	1.0	1.0	.75E-01	.49E-01
2	1.0	1.0	.74E-01	.48E-01
3	1.0	1.0	.70E-01	.43E-01
4	1.0	0.0	.69E-01	.0
5	1.0	0.0	.69E-01	.0
6	1.0	0.0	.69E-01	.0
7	1.0	0.0	.69E-01	.0
8	1.0	0.0	.69E-01	.0
9	1.0	0.0	.69E-01	.0
10	1.0	0.0	.69E-01	.0
11	1.0	1.0	.70E-01	.43E-01
12	1.0	1.0	.74E-01	.48E-01
ROW				
1	1.0	1.0	.75E-01	.49E-01
2	1.0	1.0	.74E-01	.48E-01
3	1.0	1.0	.70E-01	.43E-01
4	1.0	0.0	.69E-01	.0
5	1.0	0.0	.69E-01	.0
6	1.0	0.0	.69E-01	.0
7	1.0	0.0	.69E-01	.0
8	1.0	0.0	.69E-01	.0
9	1.0	0.0	.69E-01	.0
10	1.0	0.0	.69E-01	.0
11	1.0	1.0	.70E-01	.43E-01
12	1.0	1.0	.74E-01	.48E-01

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PROGRAM OUTPUT, EXAMPLE 1: PAGE 19

SLIDING VELOCITY(IN/S) ACROSS ROLLER-RACE CONTACT FOR ROLLER NO. 1

SLICE NO.	====== AT OUTER RACEWAY ======			====== AT INNER RACEWAY ======		
	X	Y	Z	X	Y	Z
1	0.0	0.0	-16.3	0.0	0.0	0.0
2	0.0	0.0	-14.1	0.0	0.0	0.0
3	0.0	0.0	-11.6	0.0	0.0	0.0
4	0.0	0.0	-9.3	0.0	0.0	15.2
5	0.0	0.0	-7.2	0.0	0.0	12.1
6	0.0	0.0	-5.4	0.0	0.0	9.3
7	0.0	0.0	-3.8	0.0	0.0	6.9
8	0.0	0.0	-2.4	0.0	0.0	4.8
9	0.0	0.0	-1.3	0.0	0.0	3.0
10	0.0	0.0	-0.3	0.0	0.0	1.6
11	0.0	0.0	0.4	0.0	0.0	0.5
12	0.0	0.0	0.9	0.0	0.0	-0.2
13	0.0	0.0	1.2	0.0	0.0	-0.6
14	0.0	0.0	1.3	0.0	0.0	-0.7
15	0.0	0.0	1.1	0.0	0.0	-0.4
16	0.0	0.0	0.7	0.0	0.0	0.2
17	0.0	0.0	0.1	0.0	0.0	1.2
18	0.0	0.0	-0.7	0.0	0.0	0.0
19	0.0	0.0	-1.4	0.0	0.0	0.0
20	0.0	0.0	-3.1	0.0	0.0	0.0

PROGRAM OUTPUT, EXAMPLE 1: PAGE 20

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ROLLER SPEEDS AND DISPLACEMENTS :

ROLLER	ROLLER ROTATIONAL SPEED (RPM)	ROLLER ORBITAL SPEED (RPM)	ROLLER SKEW (RAD)	ROLLER TILT (RAD)	ACTUAL CONTACT ANGLE (DEG)	INITIAL (INPUT) CONTACT ANGLE (DEG)
ROW#1						
1	-0.7253E 04	0.1204E 04	0.0	0.1972E-03	14.16	14.17
2	-0.7256E 04	0.1204E 04	0.0	0.1792E-03	14.16	14.17
3	-0.7367E 04	0.1220E 04	0.0	0.1664E-02	14.05	14.17
4	-0.7286E 04	0.1210E 04	0.0	0.0	14.17	14.17
5	-0.7286E 04	0.1210E 04	0.0	0.0	14.17	14.17
6	-0.7286E 04	0.1210E 04	0.0	0.0	14.17	14.17
7	-0.7286E 04	0.1210E 04	0.0	0.0	14.17	14.17
8	-0.7286E 04	0.1210E 04	0.0	0.0	14.17	14.17
9	-0.7286E 04	0.1210E 04	0.0	0.0	14.17	14.17
10	-0.7286E 04	0.1210E 04	0.0	0.0	14.17	14.17
11	-0.7367E 04	0.1220E 04	0.0	0.1664E-02	14.05	14.17
12	-0.7256E 04	0.1204E 04	0.0	0.1792E-03	14.16	14.17
ROW#2						
1	0.7258E 04	0.1204E 04	0.0	0.1972E-03	14.16	14.17
2	0.7256E 04	0.1204E 04	0.0	0.1792E-03	14.16	14.17
3	0.7367E 04	0.1220E 04	0.0	0.1664E-02	14.05	14.17
4	0.7286E 04	0.1210E 04	0.0	0.0	14.17	14.17
5	0.7286E 04	0.1210E 04	0.0	0.0	14.17	14.17
6	0.7286E 04	0.1210E 04	0.0	0.0	14.17	14.17
7	0.7286E 04	0.1210E 04	0.0	0.0	14.17	14.17
8	0.7286E 04	0.1210E 04	0.0	0.0	14.17	14.17
9	0.7286E 04	0.1210E 04	0.0	0.0	14.17	14.17
10	0.7286E 04	0.1210E 04	0.0	0.0	14.17	14.17
11	0.7367E 04	0.1220E 04	0.0	0.1664E-02	14.05	14.17
12	0.7256E 04	0.1204E 04	0.0	0.1792E-03	14.16	14.17

EPICYCLIC CASE SPEED (FOR REFERENCE, RPM) - 1210.

PROGRAM OUTPUT, EXAMPLE 1: PAGE 21

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**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

CAGE POCKET LOADS F (LBS) AND MOMENTS M (IN-LB):

ROLLER	F-X	F-Y	F-Z	M-X	M-Y	M-Z
ROW#1						
1	0.0	0.0	-4.55	0.0	0.0	0.0
2	0.0	0.0	-9.42	0.0	0.0	0.0
3	0.0	0.0	0.181E-01	0.0	0.0	0.0
4	0.0	0.0	0.226E-02	0.0	0.0	0.0
5	0.0	0.0	0.226E-02	0.0	0.0	0.0
6	0.0	0.0	0.226E-02	0.0	0.0	0.0
7	0.0	0.0	0.226E-02	0.0	0.0	0.0
8	0.0	0.0	0.226E-02	0.0	0.0	0.0
9	0.0	0.0	0.226E-02	0.0	0.0	0.0
10	0.0	0.0	0.226E-02	0.0	0.0	0.0
11	0.0	0.0	0.181E-01	0.0	0.0	0.0
12	0.0	0.0	-9.42	0.0	0.0	0.0
ROW#2						
1	0.0	0.0	4.55	0.0	0.0	0.0
2	0.0	0.0	9.42	0.0	0.0	0.0
3	0.0	0.0	-0.181E-01	0.0	0.0	0.0
4	0.0	0.0	-0.226E-02	0.0	0.0	0.0
5	0.0	0.0	-0.226E-02	0.0	0.0	0.0
6	0.0	0.0	-0.226E-02	0.0	0.0	0.0
7	0.0	0.0	-0.226E-02	0.0	0.0	0.0
8	0.0	0.0	-0.226E-02	0.0	0.0	0.0
9	0.0	0.0	-0.226E-02	0.0	0.0	0.0
10	0.0	0.0	-0.226E-02	0.0	0.0	0.0
11	0.0	0.0	-0.181E-01	0.0	0.0	0.0
12	0.0	0.0	9.42	0.0	0.0	0.0

PROGRAM OUTPUT, EXAMPLE 1: PAGE 22

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CAGE RAIL AND SPLIT CAGE DATA

CAGE RAIL TO RING LAND FORCES (LBS)

PIECE #1			PIECE #2		
FX	FY	FZ	FX	FY	FZ
0.0	0.0	0.0	0.0	0.0	0.0

	PIECE #1	PIECE #2
LAND INDUCED TORQUE (IN-LB)	0.0	0.0

CAGE SPEED, ROW 1 (RPM)	1210.4
CAGE SPEED, ROW 2 (RPM)	1210.4
CAGE WEIGHT(LB)	0.0
TORQUE AT SPLIT INTERFACE(IN-LB)	0.0
HEAT GENERATED AT SPLIT(WATTS)	0.0
CAGE CENTRIFUGAL LOAD(LB)	0.0
EPICYCLIC CAGE SPEED(FOR REF., RPM)	1210.4
CAGE TO SHAFT SPEED RATIO, ROW 1	0.403
CAGE TO SHAFT SPEED RATIO, ROW 2	0.403

PROGRAM OUTPUT, EXAMPLE 1: PAGE 23

**** SPHERHEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

T E M P E R A T U R E   M A P

TEMPERATURES ARE IN DEGREES CELSIUS. THE FIRST 44 TEMPERATURES ARE CALCULATED, THE OTHERS ARE KNOWN

STEADY STATE TEMPERATURE CALCULATION, FINAL RESULT AFTER 2 ITERATIONS

CALCULATED TEMPERATURES

NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE
1	97.337	2	101.450	3	101.522	4	103.739	5	109.486
6	103.724	7	109.794	8	106.950	9	106.950	10	109.158
11	103.158	12	106.892	13	106.892	14	104.457	15	103.010
16	103.985	17	101.956	18	101.970	19	102.295	20	101.863
21	96.915	22	106.493	23	103.452	24	107.592	25	109.499
26	110.175	27	110.989	28	109.775	29	109.358	30	106.910
31	106.910	32	104.068	33	112.594	34	112.015	35	112.015
36	95.326	37	97.753	38	98.185	39	103.370	40	102.007
41	102.014	42	97.994	43	99.988	44	106.956		

KNOWN BOUNDARY TEMPERATURES

NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE
45	93.000	46	100.000	47	26.700	48	102.000	49	138.000
50	93.300								

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PROGRAM OUTPUT, EXAMPLE 1: PAGE 24

APPENDIX D

SPHERBEAN OUTPUT, EXAMPLE PROBLEM 2

**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

SURFACE FINISH AND FATIGUE LIFE DATA :

RMS SURFACE ROUGHNESS (IN)

OUTER RING	INNER RING	ROLLER
0.62500E-05	0.62500E-05	0.62500E-05

PLANETARY BEARING ANALYSIS DATA :

CROSS SECT. MOMENT OF INERTIA OF OUTER RING (IN-4)	RADIUS TO NEUTRAL AXIS (IN)	CARRIER SPEED (RPM)	OUTER RING SPEED (RPM)	INNER RING SPEED (RPM)	ANGLE BETWEEN GEAR TEETH (RAD)	RADIUS FROM SUN GEAR TO POST (IN)
0.15700	3.11720	0.0	0.32310E 04	0.0	0.0	6.70000

GEAR ELASTIC MODULUS (PSI)	GEAR DENSITY (LB/IN3)	GEAR WEIGHT (LBF)	NO. OF TEETH IN CONTACT
0.29500E 09	0.28000	11.07000	1

PLANET GEAR LOADING DATA :

MESH NO.	RADIAL LOAD (LBS)	TANGENT LOAD (LBS)	MOMENT LOAD (IN-LBS)
1	-2710.	5810.	4200.

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PROGRAM OUTPUT, EXAMPLE 2: PAGE 1

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**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

          INNER RING APPLIED FORCES AND MOMENTS     (LBS, IN-LB, IN) :

PLANETARY LOADS :
                         AT GEAR MESH NO.     1

     RADIAL LOAD     -.2710E 04      0.0          0.0
     TANGENT LOAD    0.5913E 04      0.0          0.0
     MOMENT LOAD     0.4200E 04      0.0          0.0

     RADIAL MISALIGNMENT (Y) =       0.0

     RADIAL MISALIGNMENT (Z) =       0.0


     CENTRIFUGAL FORCE       =       0.0


     POST LOAD (X) =       0.0

     POST LOAD (Y) =       0.1150E 05

     POST LOAD (Z) =       0.0

               INNER RING REACTIVE FORCES AND MOMENTS

                      X              Y              Z
     LOAD        0.5471D-12     -0.1170D 05    0.2307D 03
     MOMENT      0.7161D 03      0.1354D-13    0.6128D-13



          OTHER CALCULATED OUTPUT :

PITCH DIAMETER               OSCULATION
                      OUTER RING        INNER RING
     (IN)

     4.532            0.5735            0.5740
```

PROGRAM OUTPUT, EXAMPLE 2, PAGE 2

**** SPHERBEAN/NASA - SKF INDUSTRIES - TECHNOLOGY SERVICES - SKF INDUSTRIES - SPHERBEAN/NASA ****

DEFLECTIONS OF THE OUTER RING AT SPECIFIC ROLLER LOCATIONS (IN)

ROW#1 ROLLER		ROW#2 ROLLER	
1	0.1049E-02	1	0.1048E-02
2	0.8978E-03	2	0.8978E-03
3	0.3893E-03	3	0.3893E-03
4	-0.3377E-03	4	-0.3377E-03
5	-0.1066E-02	5	-0.1056E-02
6	-0.1449E-02	6	-0.1449E-02
7	-0.8624E-03	7	-0.8624E-03
8	0.1715E-03	8	0.1715E-03
9	0.1064E-02	9	0.1064E-02
10	0.1414E-02	10	0.1414E-02
11	0.1094E-02	11	0.1094E-02
12	0.2182E-03	12	0.2182E-03
13	-0.7916E-03	13	-0.7916E-03
14	-0.1384E-02	14	-0.1394E-02
15	-0.1053E-02	15	-0.1063E-02
16	-0.4105E-03	16	-0.4105E-03
17	0.2760E-03	17	0.2760E-03
18	0.8113E-03	18	0.8113E-03

PROGRAM OUTPUT, EXAMPLE 2: PAGE 3